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The Sedimentology and Stratigraphy of the Chilhowee Group (Uppermost Proterozoic to Lower Cambrian) of Eastern Tennessee and Western North Carolina: The Evolution of the Laurentian - Iapetos Margin

James Daniel Walker
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by James Daniel Walker entitled "The Sedimentology and Stratigraphy of the Chilhowee Group (Uppermost Proterozoic to Lower Cambrian) of Eastern Tennessee and Western North Carolina: The Evolution of the Laurentian - Iapetos Margin." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Geology.

Steven G. Driese, Major Professor

We have read this dissertation and recommend its acceptance:

R. D. Hatcher, William F. Kane, Kenneth R. Walker

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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THE SEDIMENTOLOGY AND STRATIGRAPHY OF THE CHILHOWEE GROUP (UPPERMOST PROTEROZOIC TO LOWER CAMBRIAN) OF EASTERN TENNESSEE AND WESTERN NORTH CAROLINA: THE EVOLUTION OF THE LAURENTIAN - IAPETOS MARGIN

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

James Daniel Walker

May 1990

This dissertation is dedicated to my family and especially to my best friend, Alison Pouncey, for appreciating what they didn't always understand. Does any other human quality more embody the true philosophy of science?

ACKNOWLEDGMENTS

The research described in this document represents not only my efforts, but those of numerous geologists whose collective efforts represent untold years of study of the Laurentian - Iapetos margin. Without these previous studies this work would not have been possible.

This research was funded in part by grants from the Southeastern Section of the Geological Society of America, the Appalachian Basin Industrial Association, and the Discretionary Fund of the Department of Geological Sciences, The University of Tennessee. Permission to work within the boundaries of the Great Smoky National Park and Pilot Mountain State Park was granted by the U.S. Department of the Interior and the North Carolina Division of Parks and Recreation, respectively. I also wish to thank Dr. R.D. Hatcher, Jr. for allowing me extensive access to his computer facilities.

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ABSTRACT

The Blue Ridge and Piedmont provinces of the southern Appalachians possess Upper Proterozoic and Lower Paleozoic age sedimentary, metasedimentary, volcanic, and metavolcanic rock thought to represent sedimentation and igneous activity related to the formation of the Iapetos (Proto-Atlantic) ocean. These sequences of strata can be related to the development of the Laurentian - Iapetos margin as seen in the Southern Appalachians. "Rift" phase sequences of the western Blue Ridge, include the Late Proterozoic age Mount Rogers, Catoctin, Grandfather Mountain formations, and the Ocoee Supergroup, which have been interpreted by other workers as representing volcanism and sedimentation in regionally discontinuous, fault-bounded basins. Possible coeval sedimentation on the newly formed continental slope and rise, has been interpreted as resulting in the deposition of the fine-grained Ashe, Lynchburg, and Tallulah Falls formations of the eastern Blue Ridge and Inner Piedmont. The distribution of thickness and facies of upper Proterozoic and early Paleozoic sedimentary and volcanic rock have been interpreted as reflecting the development of an irregular continental margin. Throughout the western Blue Ridge province these sequences are overlain by the Chilhowee Group. The Chilhowee Group is a terrigenous clastic succession that records the stabilization of the Laurentian continental margin following Late Proterozoic rifting and formation of the Iapetos ocean. This stabilization was associated with a change from fluvial sedimentation (lower portions of the Cochran and Unicoi Formations - coeval formations of the basal Chilhowee Group) to marine sedimentation (uppermost Cochran and Unicoi Formation as well as the overlying Hampton and Nichols Formations and the Nebo, Murray, Hesse, and Helenmode Formations and their northeastern equivalent, the Erwin Formation). Examination of the Chilhowee Group at seven localities in East Tennessee (five as part of this study) has resulted in numerous refinements of our understanding of the Late Proterozoic to Early Cambrian evolution of the Laurentian margin.

Based on the recent suggestions of Crimes that trace fossils can be used to assist in correlating the Precambrian-Cambrian boundary interval in stratigraphic sequences in which diagnostic body fossils are lacking, a late Vendian? to early Placentian-equivalent (sub-Tommotian-equivalent) age is assigned to the Cochran and Unicoi Formations. An early late Placentian-equivalent (early to late Tommotian-equivalent) age is assigned to the Nichols and Hampton Formations and the lower and middle Nebo Formation . Finally, a late Placentian-equivalent or younger (Atdabanian-equivalent or younger) age is assigned to the upper Nebo, Murray, Hesse and Helenmode Formations . The Precambrian-Cambrian

boundary is probably located somewhere within the uppermost portion of Cochran-Unicoi interval. Because the Cochran-Unicoi is predominantly a coarse-grained, feldspathic terrestrial (braided fluvial/alluvial) sequence, the precise location of the Precambrian-Cambrian boundary may never be determined in the southern Appalachian region.

Variability along strike in Chilhowee facies has been recognized within the confines of the fluvial-to-marine transition. Facies identified across East Tennessee localities cross formational boundaries; thus, a facies analysis provides a practical basis for studying patterns of Chilhowee sedimentation.

Throughout East Tennessee, six facies were recognized: the **conglomerate facies**, the **interlaminated mudstone-sandstone facies**, the **sandstone facies**, the **siltstone-mudstone facies**, the **hummocky facies**, and the **quartz arenite facies**. The fluvially dominated conglomerate facies represents deposition within a braided stream system, and is typical of the basal Chilhowee Group throughout the outcrop belt. Associated with the conglomerate facies is the interlaminated mudstone-sandstone facies, which represents lacustrine deposition within a braidplain subenvironment of the braided stream system.

Above the fluvially dominated basal Chilhowee, variability along strike increases in the marine-dominated facies. The hummocky, sandstone, and quartz arenite facies consist of interbedded conglomerate, sandstone, siltstone, and mudstone exhibiting fairweather- and storm-wave produced sedimentary structures. Sedimentation occurred in an offshore, storm-dominated shelf, which received progradational pulses of sand (quartz arenite facies) from a craton-ward source.

Variations in relative abundance and stratigraphic position of shelf facies (hummocky and mudstone-siltstone facies), grain-size, and bed-thickness within the Chilhowee Group represent variations in coeval Chilhowee paleoenvironments along strike, attributable to differences in progradation versus transgression at the continental margin. Dispersion of lower Chilhowee Group paleocurrent modes suggest that topographic irregularities, possibly inherited from rifting, may have established initial sedimentary dispersal systems, which influenced later shelf facies variations. With passive-margin stabilization, paleocurrent modes assumed a more uniform pattern of cratonic sediment dispersal to the east. Examination of the available structural data as well as the distribution of facies described above suggest that present day structural strike in the area does not coincide with the latest Proterozoic to Early Cambrian depositional strike. Trends in proximality (with respect to the craton) can be characterized as representing both a northwest to southeast gradient, *and* a northeast to southwest gradient. This geometry is consistent with previous suggestions of Rankin and Thomas, that the southern strike belts occupied a position within an embayment, while the northeastern strike belts occupied a position adjacent to or within a promontory (Tennessee embayment and Virginia promontory, respectively).

Examination and point-counting of samples (n=112) collected from basal Chilhowee Group strata (Unicoi and Cochran Formations) indicates that the majority of framework grains were derived from underlying Proterozoic rocks. Variation along strike in the relative abundances of the various framework grains, the gross thickness of basal Chilhowee strata, and the restriction of rift-related basaltic volcanism to northeastern exposures are interpreted here as the result of diachronous rifting. Based on regional stratigraphic and sedimentologic patterns, two stages of rifting can be recognized: 1) a Late Proterozoic event giving rise to the numerous Late Proterozoic sequences across the area. This rift stage was followed by a period of tectonic quiescence when sedimentation patterns may have been dominated by thermal subsidence; and 2) a latest Proterozoic to Early Cambrian rifting event which was restricted to the area adjacent to the Virginia promontory.

Recent mapping in the metamorphic core of the southern Appalachians has led to the identification of several internal basement massifs interpreted as windows exposing parautochthonous basement beneath the main thrust sheet. In many instances this parautochthonous basement possesses a metasedimentary cover sequence. One such internal massif is exposed in the Piedmont of North Carolina by the Sauratown Mountains window. Here, the 1.2 Ga basement is overlain by a cover sequence of metaarkose, schist, and quartzite. The westernmost of the quartzite bodies is exposed on Pilot Mountain in Surry County, North Carolina. Lithologic and stratigraphic similarities between the sedimentary sequence at Pilot Mountain and the Chilhowee Group of eastern Tennessee, have prompted some to propose stratigraphic equivalence.

Despite amphibolite-facies regional metamorphism and multiple periods of deformation, the quartzite of Pilot Mountain displays a diverse array of primary sedimentary features. Detailed examination of the primary structures preserved within the quartzite at Pilot Mountain resulted in the delineation of three facies interpreted as representing inner shelf to foreshore marine deposition. In view of the regional west to east gradient in Chilhowee Group sedimentation described above, the quartzite at Pilot Mountain (which possesses a stratigraphic thickness exceeding 45 m) *does not* appear to represent a distal shelf portion of this passive margin sequence. Palinspastic cross-sections through the Appalachian orogen indicate that the sedimentary sequences exposed within the Sauratown Mountain window and East Tennessee occupy the same relative positions with respect to the Laurentian continental margin today as they did when they where deposited. Two possible paleogeographic - paleotectonic interpretations then seem plausible: 1) the quartzites of the Sauratown Mountains window represent Late Proterozoic, Ashe Formation-equivalent deposition along a sea-floor high associated with the partially or fully rifted basement terrane. In this case subsequent orogenic activity would have resulted in the over-thrusting of the massif and the cover by the finer-grained, offshore deposits of the Ashe Formation, 2) the quartzites of the Sauratown Mountains window represent latest Proterozoic to Early Cambrian (Chilhowee Group time-equivalent) deposition on an isolated, rifted continental fragment. Bathymetric shallowing along the flanks of basement block would result in the deposition of shallow-water sediments derived primarily from the rifted Grenville basement block.

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CHAPTER 1

INTRODUCTION AND OVERVIEW

Studies of modern passive continental margins have become more numerous and refined in the last twenty years, leading to an ever-increasing understanding of their dynamics and evolution (Scrutton, 1982). The transition from continental rift to passive margin is significant in terms of our understanding of both continental margin evolution and the sedimentology and stratigraphy produced in these genetically related regimes. This study represents an attempt to understand the evolution of the Late Proterozoic to Early Cambrian Laurentian continental margin in the southern Appalachians, as it evolved in response to the inception and development of the Iapetos (Proto-Atlantic) ocean.

Comparison of modern rift and passive margin sequences and the exhumed counterparts is not always easy or possible. This difficulty arises from a number of factors including: 1) the proliferation, and occasional misuse, of a wide variety of terms (e.g., rift-to-drift, rift-to-passive margin, and break-up); 2) incompatibility of the various methods used to study modern settings as opposed to their exhumed counterparts (e.g., seismic reflection and refraction profiling versus mapping and outcrop-scale examination); and 3) interpretations based on only one or two lines of evidence that commonly yield results that are difficult to reconcile with other studies using different methods (e.g., regional stratigraphy versus subsidence modeling). The conclusions drawn here, therefore, represent an attempt to use modern concepts of sedimentology and sedimentary petrology, while attempting to constrain interpretations by integrating data from the surrounding regions and studies using diverse approaches.

This document represents a compilation of a number a different studies which together constitute the dissertation. The individual chapters that follow are versions of five separate manuscripts, three of these have already appeared in print (Chapter 3, Walker and others, 1988; Chapter 4, Walker and others, 1989; and Chapter 6, Walker, 1988), one is in press at the time of this writing (Chapter 2, Walker and Driese, in press), and one is in preparation (Chapter 5, Walker and Simpson, in preparation). These chapters do not represent segments of a single document *per se*, but are intended to be separate discussions of different aspects of the evolution of the Late Proterozoic to Early Cambrian Laurentian - Iapetos margin as recorded by the Chilhowee Group and related strata of eastern Tennessee and western North Carolina. As such, these chapters contain some repetition of material which by its very nature is pertinent to each discussion. The reader, therefore, is urged to view this work as it was intended, a series of separate discussions with a central theme. This work is not necessarily designed to be read from start to finish, nor is the particular order of presentation of the various topics to be construed as anything but an editorial convenience. Readers familiar with southern Appalachian stratigraphy may decide to read only specific chapters dealing with topics of special interest to them. Those unfamiliar with either southern Appalachian stratigraphy in general, or the Chilhowee Group in particular may wish to read Chapter 6 first, as this chapter represents an examination of the tectono-stratigraphic significance of Upper Proterozoic to Early Cambrian strata in the region, based in part on previous studies as well as data obtained during the studies described in the preceding chapters. Chapter 6, therefore, is a broader treatment of this portion of southern Appalachian geologic history, in terms of both its regional and temporal perspective. Chapters 2 through 5 deal with fairly specific topics including: 1) constraints on the position of the Precambrian-Cambrian boundary and its pertinence to Chilhowee Group deposition (Chapter 2); 2) sedimentology and facies architecture of the fluvial-to-marine transition recorded by the Chilhowee Group (Chapter 3); 3) the sedimentology the quartzite of the Sauratown Mountain window (a sedimentary sequence similar to portions of the Chilhowee Group in terms of its gross lithostratigraphy, that lies nonconformably upon a Grenvillian age internal basement massif; Hatcher, 1984; Hatcher and others, 1988; Chapter 4); 4) sandstone petrology and provenance of the basal Chilhowee Group in Tennessee and southern Virginia (Chapter 5).

One final comment with regard to the nature of this dissertation. Because these chapters represent (in varying degree) versions of manuscripts in different stages of publication, they are in part collaborative work. I then feel that recognition should be paid to my various co-authors, including: Dr. S.G. Driese (manuscript versions of Chapters 2, 3, and 4); Dr. R.D. Hatcher, Jr., (manuscript version of Chapter 4); Dr. E. L. Simpson (manuscript version of Chapter 5), and M.L. Cudzil and R.L. Skelly (manuscript version of Chapter 3). I am, however, the senior author of all versions and take full responsibility for the contents of this document. I believe that only the rare thesis or dissertation is truly the sole work of one individual, I therefore believe that this format allows for the timely publication of my work while truly acknowledging the efforts of my colleagues.

CHAPTER 2

CONSTRAINTS ON THE POSITION OF THE PRECAMBRIAN-CAMBRIAN BOUNDARY IN THE SOUTHERN APPALACHIANS

INTRODUCTION

Much recent research has focused on establishing the position of the Precambrian-Cambrian boundary at various localities worldwide. An excellent summary of the problems involved in the determination of this major boundary is provided by Sepkoski and Knoll (1983), Cowie and Johnson (1985), and Conway Morris (1987). Twenty years ago the boundary was placed at the base of stratigraphic units containing the first trilobite body fossils. Trace fossils (arthropod and others) were later discovered stratigraphically beneath the lowest occurrence of trilobites (e.g., Alpert, 1975; 1977; Crimes and others, 1977; see Crimes (1987) for a complete summary). Most recent has been the discovery, first in the Soviet Union and then elsewhere, of a pre-trilobite shelly fossil assemblage which commonly occurs stratigraphically beneath the zone of arthropod trace fossils and trilobite body fossils, (e.g., Raaben, 1969; Bengtson and Fletcher, 1983; Mount and others, 1983; McMenamin and others, 1983; Gevirtzman and Mount, 1986; Signor and others, 1987; Culver and others, 1988; Landing, 1988). This sub-trilobite fossil assemblage has led to the definition of the basal Cambrian Tommotian-equivalent stage, in which the lowest occurrence of these problematic fossils defines the Precambrian-Cambrian boundary. Subsequent discovery of small shelly fossils in rocks stratigraphically below Tommotian-equivalent strata in the Avalon of New England and Newfoundland has led to the definition of the Placentian Series (Landing, 1988; Landing and others, 1989). The Placentian Series (lowest Cambrian) then constitutes strata that contain sub-trilobite body fossils (Nemakit Daldyn-equivalent through Atdabanian-equivalent stages).

In the southern Appalachians, the Precambrian-Cambrian boundary has been arbitrarily placed at the base of the Chilhowee Group based on perceived lithologic and stratigraphic differences, in spite of the fact that deposition in some areas has been viewed as more or less continuous across the boundary (King, 1949). Other researchers have chosen to assign the upper portion to the Early Cambrian and the lower part to the Early

Cambrian (?) (Laurence and Palmer, 1963; Palmer, 1971), or as Early Cambrian and late Precambrian, respectively (Schwab, 1972; Bond and others, 1984; Fichter and Diecchio, 1986).

Our purpose is to summarize the recent results of research conducted on the sedimentology and paleoenvironments of the Chilhowee Group (latest Proterozoic to Early Cambrian) in eastern Tennessee (Cudzil, 1985; Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988) which are pertinent to the Precambrian-Cambrian boundary problem and to compare these results with data obtained from recent studies in southwestern Virginia (Simpson and Sundberg, 1987; Simpson and Eriksson, 1989; 1990).

LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

General Setting

The Chilhowee Group is exposed in a series of discontinuous strike belts along the western margin of the Blue Ridge from Alabama to Vermont (Fig. 2-1; Rodgers, 1963; Schwab, 1972; Mack, 1980) and consequently possesses a complex stratigraphic nomenclature (Fig. 2-2). In the southern Appalachian region the Chilhowee Group is a 600-1500 m thick sequence of interbedded feldspathic conglomerate, feldspathic and quartzose sandstone, micaceous siltstone, and shale (Walker and others, 1988). Chilhowee Group strata in this area have been interpreted as representing the transition from sedimentation within a continental rift system (Rast and Kohles, 1986) to a passive margin setting associated with the opening of the Iapetos (Proto-Atlantic) ocean (Hatcher, 1972, 1978; Rankin, 1975, 1976). The basal Chilhowee Group overlies Grenvillian basement in some regions and Upper Proterozoic metasedimentary and metavolcanic sequences elsewhere (Fig. 2-2). This lower interval, which comprises the Cochran-Unicoi and equivalent formations, probably represents deposition on attenuated continental crust along a tectonically inactive, thermally subsiding continental margin in southern Tennessee (Cochran Formation) and coeval sedimentation associated with active extension (synrift deposition) in northeast Tennessee and southeastern Virginia (Unicoi Formation; Simpson and Eriksson, 1989; Walker, 1990). Continental promontories and embayments inherited from Late Proterozoic rifting, which may have influenced

FIG. 2-1. - Outcrop distribution (shaded black) of Chilhowee Group rocks along western margin of Blue Ridge Province. Numbers 1, 2 and 3 denote Bean Mountain, Chilhowee Mountain and Valley Forge (Doe River Gorge locality of Cudzil and Driese, 1987) localities, respectively, which are discussed in text. Number 4 denotes the location of section in southwestern Virginia studied by Simpson and Sundberg (1987).

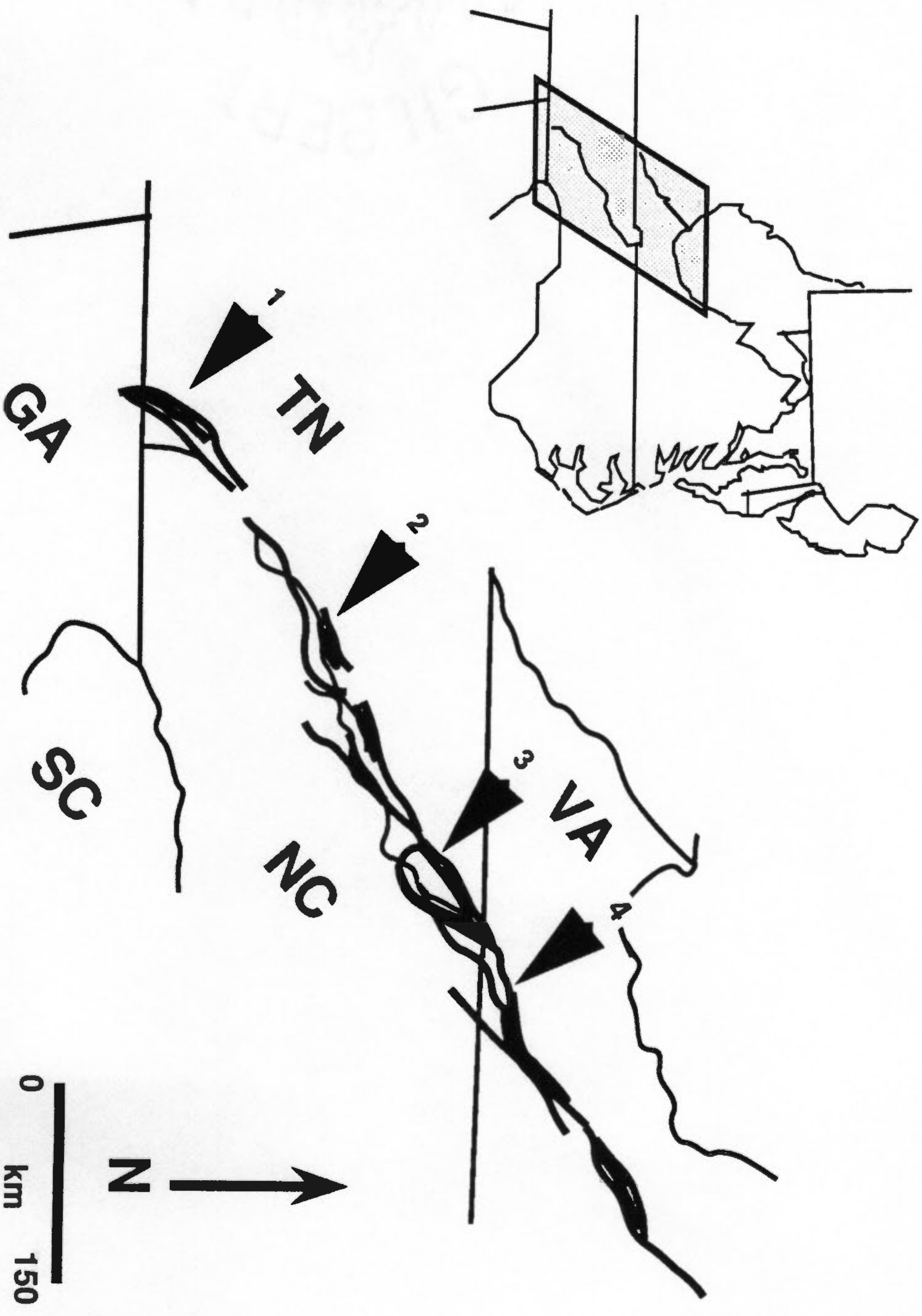

GA
TN
SC
NC
VA
1
2
3
4
N
0
km
150

FIG. 2-2. - Stratigraphic nomenclature for the Chilhowee Group. Modified from Schwab (1972) and Mack (1980).

<table>
<tr><th>AGE</th><th colspan="2">North Georgia and Alabama</th><th colspan="2">Southeastern Tennessee</th><th colspan="2">Northeastern Tennessee</th><th>Southwestern Virginia</th><th>Northwestern Virginia</th></tr>
<tr><td rowspan="8">EARLY CAMBRIAN</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td>Shady Dolomite</td><td>Tomstown Dolomite</td></tr>
<tr><td rowspan="7">CHILHOWEE GROUP</td><td rowspan="2">Weisner Formation</td><td colspan="2">Helenmode Formation</td><td rowspan="4">Erwin Formation</td><td>Helenmode Member</td><td rowspan="4">Erwin Formation</td><td rowspan="4">Antietam Quartzite</td></tr>
<tr><td colspan="2">Hesse Quartzite</td><td>Hesse Quartzite Member</td></tr>
<tr><td rowspan="2">Wilson Ridge Formation</td><td colspan="2">Murray Shale</td><td>Murray Shale Member</td></tr>
<tr><td colspan="2">Nebo Quartzite</td><td>Nebo Quartzite Member</td></tr>
<tr><td>Nichols Shale</td><td colspan="2">Nichols Shale</td><td colspan="2">Hampton Shale</td><td>Hampton Shale</td><td>Harpers Formation</td></tr>
<tr><td rowspan="2">Cochran Formation</td><td colspan="2" rowspan="2">Cochran Formation</td><td colspan="2" rowspan="2">Unicoi Formation</td><td rowspan="2">Unicoi Formation</td><td>Weaverton Quartzite</td></tr>
<tr><td>Loudon Formation</td></tr>
<tr><td>— ?- —
PROTEROZOIC</td><td colspan="2">base of section always faulted out</td><td>Ocoee Supergroup</td><td>Sandsuck Formation</td><td colspan="2">Mount Rogers Volcanic Group or Grenville basement</td><td>Mount Rogers Volcanic Group</td><td>Catoctin Greenstone or Swift Run Fm. or injection complexes</td></tr>
</table>

basal Chilhowee Group sedimentation (Skelly and others, 1987; Walker and others, 1988; Simpson and Eriksson, 1989; Walker, 1988; see Chapters 5 and 6 for discussion), have been proposed by Thomas (1977, 1983). Deposition of the overlying Hampton/Erwin and equivalent formations has been interpreted to have taken place on a stabilized, thermally subsiding continental margin (Fichter and Diecchio, 1986; Walker and others, 1988; Walker, 1988). Paleocurrent data from numerous sources indicate a predominantly westward source and detrital sediment prograded eastward over attenuated continental crust (Schwab, 1970, 1971, 1972; Brown, 1970; Whisonant, 1970, 1974; Mack, 1980; Cudzil, 1985; Skelly, 1987; Cudzil and Driese, 1987; Simpson and Eriksson, 1990). Consequently, earlier workers have tentatively interpreted the basal Chilhowee deposits as representing fluvial or coastal alluvial sedimentation, whereas the upper sequences have been interpreted as representing shallow-marine (foreshore, shoreface and shelf) deposition (Schwab, 1970, 1971, 1972; Whisonant, 1974; Mack, 1980; Cudzil and Driese, 1987; Simpson and Eriksson, 1989; 1990; Walker and others, 1988, see Chapter 3 for discussion).

Stratigraphic Relations in eastern Tennessee

The Chilhowee Group has been subdivided into six formations in eastern Tennessee (Fig. 2-2). In northern outcrop belts (Fig. 2-2), the Chilhowee is extraordinarily thick and overlies Grenvillian basement (0.9-1.1 Ga) with nonconformity; the Chilhowee is somewhat thinner in central and southern outcrop belts (400 m as opposed to 1000 m in the northeast Tennessee, Walker and others, 1988) and overlies the Upper Proterozoic Ocoee Supergroup, a 5-12 km thick synrift to thermally? subsiding basin sequence (Hadley, 1970; Knoll and Keller, 1979; Rast and Kohles, 1986) of highly immature conglomerate, sandstone, siltstone which changes upsection into texturally more mature sandstone and shale with minor conglomerate and rare carbonate units (Fig. 2-3). The contact with the overlying Chilhowee Group appears conformable in southeast Tennessee but the basal conglomerate of the Unicoi Formation in the Hot Springs window of North Carolina contain clasts identical to lithologies of the immediately underlying Sandsuck Formation (uppermost unit of the Walden Creek Group of the Ocoee Supergroup; see Chapter 5 for discussion). The basal contact therefore changes from conformable to slightly disconformable along depositional strike from southwest to

FIG. 2-3. - Stratigraphic nomenclature for the Ocoee Supergroup east of the Greenbrier fault. Modified from King (1964), Neuman and Nelson (1965), and Hadley (1970).

Latest Proterozoic to Early Cambrian	**Chilhowee Group**		
Late Proterozoic	**OCOEE SUPERGROUP**	Walden Creek Group	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation
		Unclassified Formation	Cades Sandstone Sandstones of Webb Mountain and Big Ridge Rich Butt Sandstone
		Snowbird Group	Metcalf Phyllite Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
Middle Proterozoic	Grenville Basement		

northeast. Rocks of the Ocoee Supergroup in Tennessee display some degree of penetrative deformation and metamorphic grade varies from sub-greenschist to greenschist (portions of the Ocoee Supergroup east and southeast of Tennessee are middle to upper Amphibolite grade). The occurrences of shallow-water carbonate lithofacies in the upper part of the Ocoee are particularly important (Yellow Breeches Member of the Wilhite Formation, Walden Creek Group; Hanselman and others; 1974) as they suggest active extension had ceased in the area before deposition of the basal Chilhowee strata. Estimates of the timing of the opening of Iapetos vary, but the most recent estimates based on dates obtained by Odom and Fullagar (1984) from the Crossnore Plutonic Series suggest rift-related magmatism began as early as 690 $\pm$ 20 Ma. Tectonism and volcanism extended into early Chilhowee time, as documented in southern Virginia and northeastern Tennessee (Simpson and Eriksson, 1989; Misra and Walker, 1990; see Chapter 5 for more discussion). Siliciclastic marine deposition recorded by the upper portion of the Chilhowee Group along the extent of the Appalachian Orogen gave way to carbonate shelf deposition represented by the overlying Shady Dolomite and its northeastern equivalents. The position of the Precambrian-Cambrian boundary is therefore directly pertinent to the determination of an upper limit to the age of Iapetos extension because of its implications for determining the age of the youngest demonstrable rift-related activity (represented by deposits of the Unicoi Formation) in the southern Appalachians Williams and Hiscott, 1987; Simpson and Sundberg, 1987; see Chapters 5 and 6 for more discussion). Hurley and others (1960) reported the only radiometric date available for the Chilhowee Group of 552 $\pm$ 30 Ma based on Rb/Sr ratios determined for glauconite samples obtained from the Murray Shale at Murray Gap, Chilhowee Mountain (Fig. 2-1). The 552 Ma date reported was calculated using a decay constant of 1.386×10^{-11} yr^{-1}, recalculation using the more widely accepted decay constant of 1.42×10^{-11} yr^{-1} yields an age of 539 $\pm$ 30 Ma (Cormier, pers. comm., 1990). Much of the critical mapping of the Chilhowee Group was provided by King and Ferguson (1960), King (1964), and Neuman and Nelson (1965).

The basal stratigraphic unit in the Chilhowee Group includes the Cochran and Unicoi Formations, and ranges from 100-200 m thick in the central and southern outcrop belts (Skelly, 1987; Walker and others, 1988) to as much as 500 m in northeastern Tennessee and southeast Virginia (Simpson and Eriksson, 1989; Cudzil and Driese, 1987; Table 2-1). Conglomerate and pebbly sandstone are abundant towards the base of the sequence, and grade upward into very coarse-grained, feldspathic sandstone (Whisonant, 1974; Walker and others, 1988). Significant occurrences of clean, massive to conspicuously planar-tabular cross-stratified quartz arenite beds occur within the upper part of the sequence (Cudzil and Driese, 1987; Simpson and Eriksson, 1989). Regional variations in paleocurrent flow vectors are interpreted as the result of an initial irregular morphology of the continental margin which was inherited from rifting (Walker and others, 1988; See Chapter 3 for more discussion). The paleoenvironment was probably that of a coastal braid plain, which carried feldspathic detritus eastward to a high-energy marine coastline where it was locally reworked into quartz arenite sequences (Cudzil and Driese, 1987; Walker and others, 1988; see Chapter 3 and 5 for more discussion).

The Nichols-Hampton Formation conformably overlies the Cochran-Unicoi sequence, and consists of about 75-275 m of thin-bedded clayey siltstone that is interstratified with very thin glauconitic feldspathic sandstone beds (Cudzil, 1985; Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988, Table 2-1). The sandstone beds display internal structures and geometries which indicate that they are storm-deposited event beds (tempestites) (Skelly, 1987; Walker and others, 1988). The depositional setting was a silt- and mud-dominated marine shelf in which storms episodically transported sand eroded from the shoreface out onto the shelf. The overall sequence thickens and coarsens upward, and, when included together with the overlying Nebo Formation composes a very large-scale shoaling-upward package (Walker and others, 1988).

The Nebo Formation (termed the Nebo Member of Erwin Formation in northeast Tennessee; Fig. 2-2) conformably overlies the Nichols-Hampton sequence, and ranges from 20-120 m in thickness (Cudzil, 1985; Skelly, 1987; Walker and others, 1988, Table 2-1). It is dominantly a medium-grained, submature quartz arenite to feldspathic arenite (Whisonant, 1974). The lower part is dominated by hummocky and low-angle cross-stratification, which grades upward into high-angle trough and planar-tabular cross-stratification, punctuated by densely bioturbated horizons dominated by *Skolithos* (Skelly, 1987; Walker and others, 1988). The paleoenvironment was probably a storm-dominated inner shelf, shoreface, and foreshore system which existed as a coeval lateral

Table 2-1. - *Stratigraphy, sedimentology and inferred depositional settings for the Chilhowee Group of the Southern Appalachians*

Formation*	Alabama/Georgia equivalent(s)	NE Tennessee/ SW Virginia equivalent(s)	Thickness (m)3	Lithologic description 2	Inferred depositional environment
Helenmode	uppermost Weisner	uppermost Erwin	N/A3 (10-15)	Fine-grained, poorly lithified and exposed thin-bedded sandstone and interbedded mud-siltstone	Sediment starved - STABILIZED SHELF
Hesse	Weisner	upper Erwin	45 (thickens toSW and NE, ave. 100-150)	Large-scale, planar-tabular cross-stratified quartz arenite. Granule lags and symmetrical ripple marks locally abundant. Typically thick-bedded with an erosional base.	subtidal sand ridge-STORM DOMINATED SHELF
Murray	Wilson Ridge	middle Erwin	60 (thickens to SW and NE, ave. 70-110)	Variaby cross-stratified, and bioturbated silt- and mudstone interbedded with varying amounts of hummocky and microhummocky feldspathic sandstone. Glauconite abundant throughout.	fairweather (mud- and siltstone) and storm (sandstone) deposition-STORM-DOMINATED SHELF
Nebo	Wilson Ridge	lower Erwin	80 (thins to SW and NE, ave. 20-50)	Medium-scale, planar-tabular and symmetrical ripple cross-stratified quartz arenite interbedded on various scales with hummocky and trough cross-stratified feldspathic sandstone. Rare asymmetric ripples and heavily bioturbated horizons observed at many localities.	subtidal sand ridge-STORM DOMINATED SHELF and/or various subenvironments associated with-SUBTIDAL CHANNELS AND SHOALS
Nichols	Nichols	Hampton	85 (thickens to SW and NE, ave. 150-175)	Variably cross-stratified, and bioturbated silt- and mudstone interbedded with varying amounts of hummocky and microhummocky feldspathic sandstone. Glauconite abundant throughout.	fairweather (mud- and siltstone) and storm (sandstone) deposition-STORM-DOMINATED SHELF
Cochran	Cochran	Unicoi	90+ (thins to SW and thickens to NE, ave. 100-400)	Lithologic nature highly variably. Overall uni fines upward. Quartz/Feldspar ratio increases upsection. Lower portion of unit is dominantly massive, large-scale planar-tabular, or megaripple cross-stratified, pebble-cobble conglomerate. Upper portion displays low-angle and large-scale planar-tabular cross-stratification.	transverse and longitudinal bar and associated subevironments-BRAIDED STREAM overlain by subtidal sand ridge-STORM DOMINATED SHELF

* Stratigraphy as descrided at Chilhowee Group type-locality at Chilhowee Mountain, Tennesee
1 Thickness listed as measured at Chilhowee Mountain followed by range over entire southern Applachians as reported by Mack (1980), Cudzil and Driese (1987), Skelly (1987), and Simps (1987)
2 Lithologic description generalized for entire southern Applachians as reported by Mack (1980), Cudzil and Driese (1987), Skelly (1987), and Simpson (1987)
3 Helenmode Formation not exposed at Chilhowee Mountain. Range of thicknesses as reported by King and Ferguson (1960), King (1964), Neuman and Nelson, (1965)Cudzil and Driese (1!

equivalent of the Nichols-Hampton outer (mud) shelf (Skelly, 1987; Walker and others, 1988).

The Murray Formation (termed the Murray Member of Erwin Formation in northeast Tennessee; Fig. 2-2) conformably overlies the Nebo Formation, and ranges from 70-105 m thick in the central and southern area (Skelly, 1987; Walker and others, 1988, Table 2-1) to about 220 m in northeastern Tennessee (Cudzil, 1985; Cudzil and Driese, 1987). It consists predominantly of thin- bedded muddy siltstone (very similar to the older Nichols Formation) interstratified with thin, feldspathic glauconitic sandstone beds that have tempestite structures and stratification sequences (Skelly, 1987; Walker and others, 1988). Rare lingulellid brachiopods, trilobites and ostracodes have been reported (Laurence and Palmer, 1963). The depositional environment of the Murray Formation was probably identical to that of the older Nichols Formation, a low-energy mud shelf that was episodically affected by storms (Skelly, 1987; Walker and others, 1988).

The 40-100 m thick Hesse Formation (termed the Hesse Member of Erwin Formation in northeast Tennessee; Fig. 2-2) conformably overlies the Murray Formation (Cudzil, 1985; Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988; Table 2-1), and consists of fine- to medium-grained, submature to mature quartz arenite that closely resembles the older Nebo Sandstone (Whisonant, 1974). Sedimentary structures are dominated by medium- to very large-scale planar-tabular cross-stratification, small- to medium-scale trough cross-stratification (some herringbone ?), and locally abundant *Skolithos* (Skelly, 1987; Walker and others, 1988). Paleoenvironmental interpretations for the Hesse Formation are similar to those proposed for the Nebo Formation and include inner shelf, shoreface and foreshore environments with a mixed storm and tidal influence. Furthermore, the Murray-Hesse package comprises a second shoaling-upward sequence that followed deposition of the Nichols-Nebo package (Skelly, 1987; Walker and others, 1988).

The 15-60 m thick Helenmode Formation (Member) conformably overlies the Hesse Formation (King and Ferguson, 1960; King, 1964; Neuman and Nelson, 1965, Table 1) and consists of very poorly exposed calcareous shale, siltstone and glauconitic sandstone (Whisonant, 1974; Cudzil, 1985). Although no exposures of this interval were examined as part of this study, earlier studies report occurrences of inarticulate brachiopods, trilobites, hyoliths, and ostracodes (Neuman and Nelson, 1965). The Helenmode is inferred to have been deposited in a shelf environment transitional between the terrigenous clastic-dominated Chilhowee shelf and the Shady Dolomite carbonate ramp (Whisonant, 1974).

BIOSTRATIGRAPHY

Trace Fossil Distribution

Valley Forge. At this locality in northeastern Tennessee (Fig. 2-1) the Chilhowee Group exhibits a three-fold stratigraphy which includes the Unicoi, Hampton, and Erwin Formations (Fig. 2-2) and is exposed within the Iron Mountain thrust sheet. Approximately 5 km to the southeast, the Chilhowee Group is exposed in the footwall of the Iron Mountain thrust and nonconformably overlies Grenvillian crystalline basement (Hampton Section of King and Ferguson, 1960). The stratigraphic distribution of trace fossils in the Chilhowee Group is shown in Figure 2-4. Note that the lowest occurrence of traces is in the basal Unicoi Formation; *Paleophycus* occurs 191 m above the base of the section in facies interpreted as representing tide-related brackish pond/lacustrine deposition (Cudzil, 1985; Cudzil and Driese, 1987; Fig. 2-4). The lowest stratigraphic occurrence of *Planolites* is in the Hampton Formation, 538 m above the base of the section (Cudzil, 1985), and *Skolithos* first appears slightly higher at 555 m (Fig. 2-4, 2-5). *Rusophycus* and *Cruziana* first appear much higher in the Erwin Formation, 936 m above the base of the section (Cudzil, 1985); both traces then occur commonly throughout the Erwin (Fig. 2-4, 2-5).

Chilhowee Mountain. The six-fold stratigraphy of the Cochran-Nichols-Nebo-Murray-Hesse-Helenmode Formations (Fig. 2-2) is best observed at Chilhowee Mountain, the type locality of the Chilhowee Group (Fig. 2-1; Safford, 1856). The faulted nature of the base of the best exposed section at this locality greatly complicates the assessment of the nature of the contact between the Chilhowee Group and the underlying Upper Proterozoic Ocoee Supergroup. Examination of natural outcrop did not result in the recognition of evidence of a disconformity along the stratigraphic contact as mapped by Neuman and Nelson (1965). The stratigraphic distribution of trace fossils in the Chilhowee Group at Chilhowee Mountain is summarized in Figure 2-6. No traces

FIG. 2-4. - Summary of trace fossil distribution in the Chilhowee Group at Valley Forge section (Locality 3 in Figure 1). Q = quartz arenite facies, H = Hummocky facies, S = sandstone facies, G = conglomerate facies. Data are from Cudzil (1985).

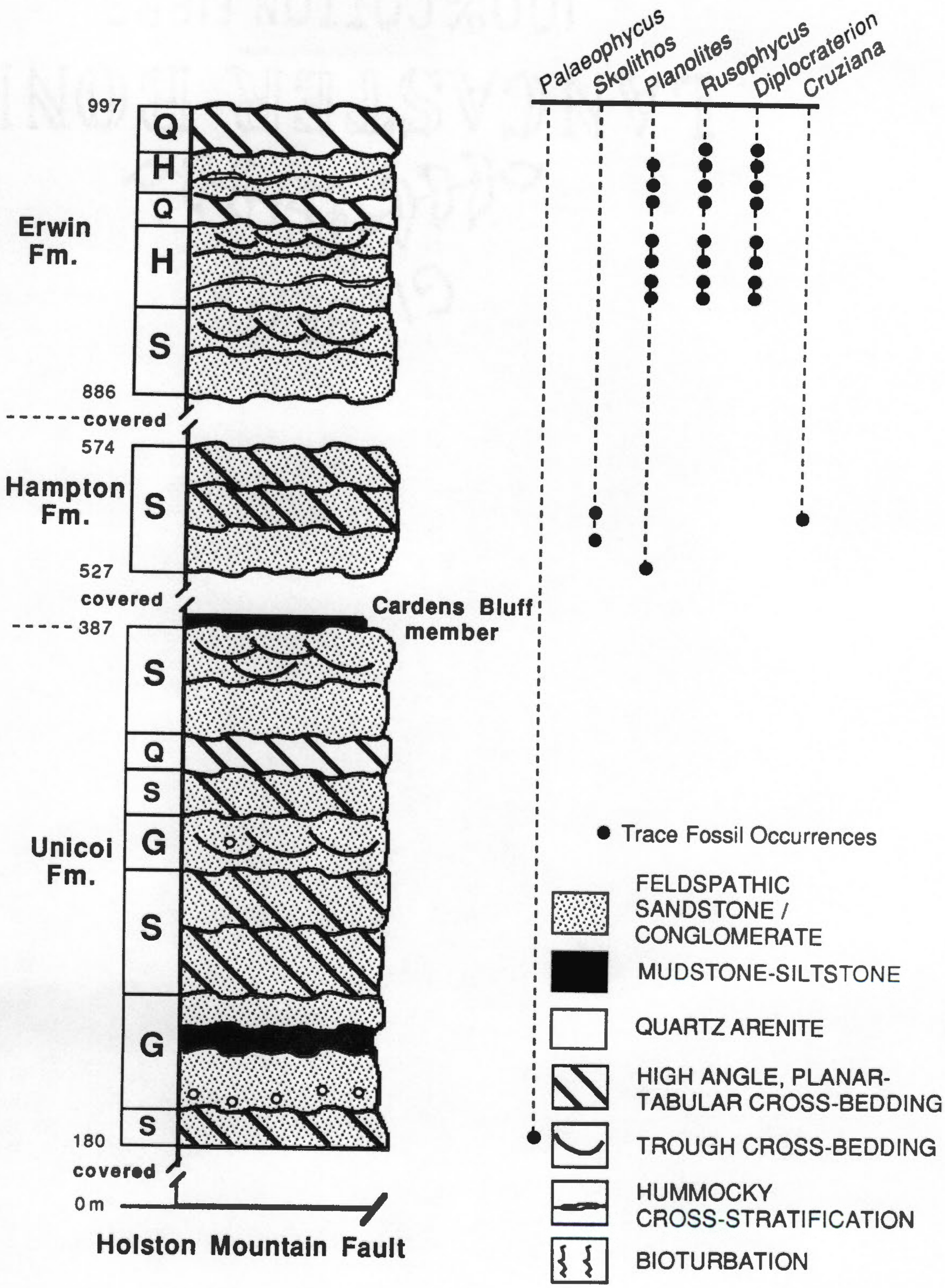

Palaeophycus
Skolithos
Planolites
Rusophycus
Diplocraterion
Cruziana
997
Q
H
Q
H
S
Erwin Fm.
886
covered
574
Hampton Fm.
S
527
covered
387
Cardens Bluff member
S
Q
S
G
Unicoi Fm.
S
G
S
180
covered
0 m
Holston Mountain Fault
Trace Fossil Occurrences
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE
HIGH ANGLE, PLANAR-TABULAR CROSS-BEDDING
TROUGH CROSS-BEDDING
HUMMOCKY CROSS-STRATIFICATION
BIOTURBATION

FIG. 2-5. - Line drawings of various trace fossils found in Upper Proterozoic to Lower Cambrian strata. From Crimes (1987).

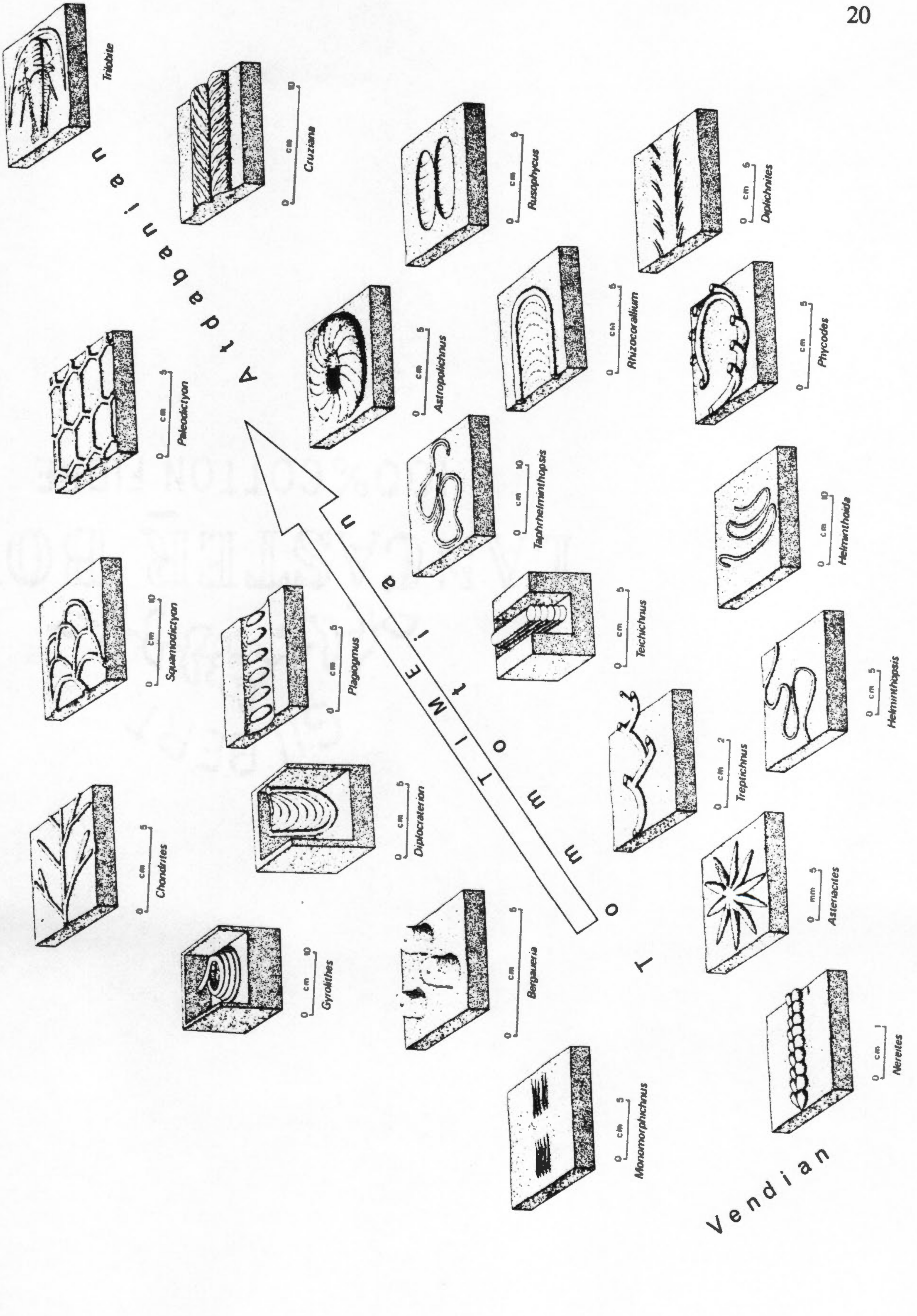
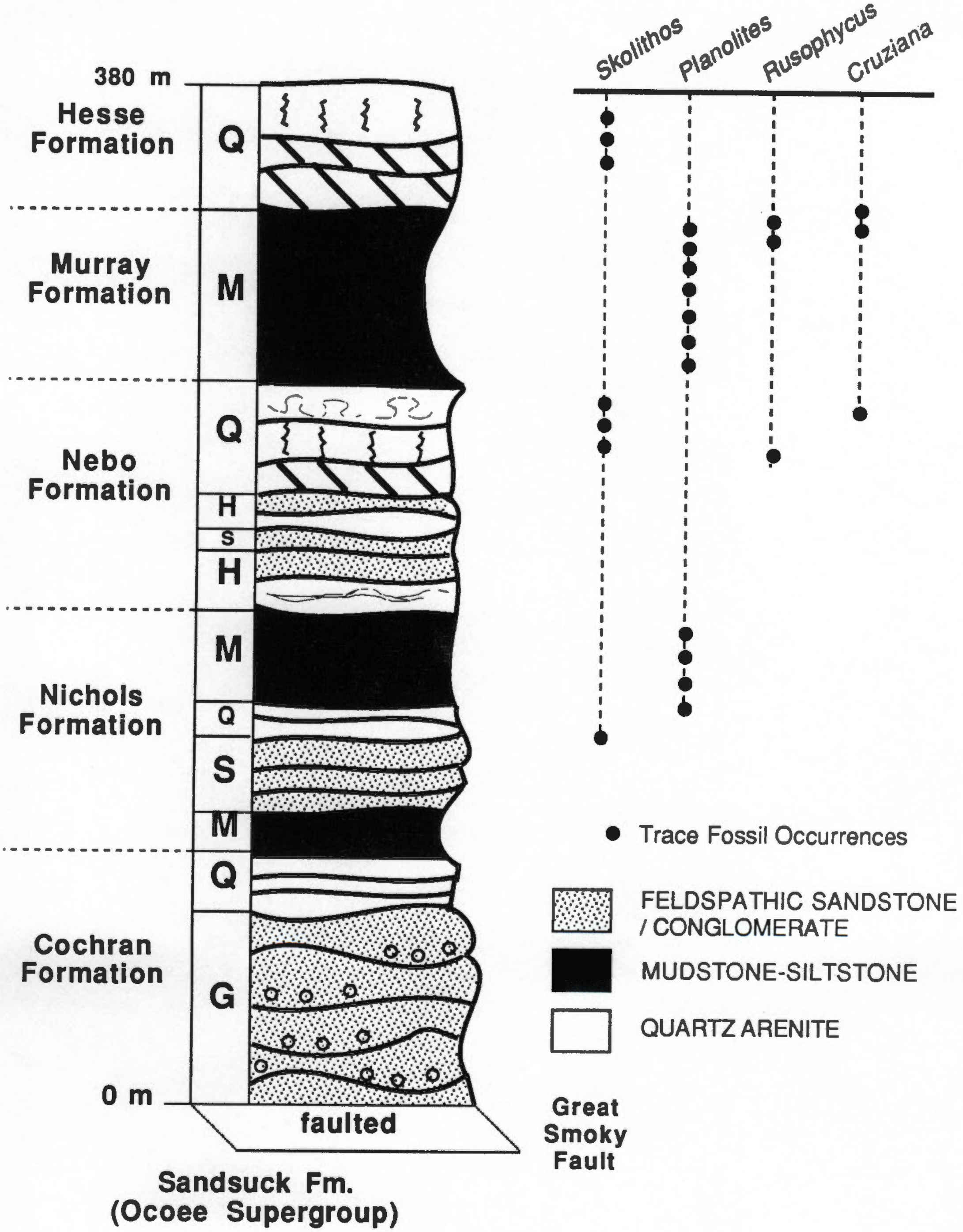

Trilobite
Cruziana
Rusophycus
Diplichnites
Paleodictyon
Astropolichnus
Rhizocorallium
Phycodes
Taphrhelminthopsis
Helminthoida
Squamodictyon
Plagiogmus
Teichichnus
Helminthopsis
Treptichnus
Chondrites
Diplocraterion
Asteriacites
Gyrolithes
Bergaueria
Nereites
Monomorphichnus
Atdabanian
Tommotian
Vendian

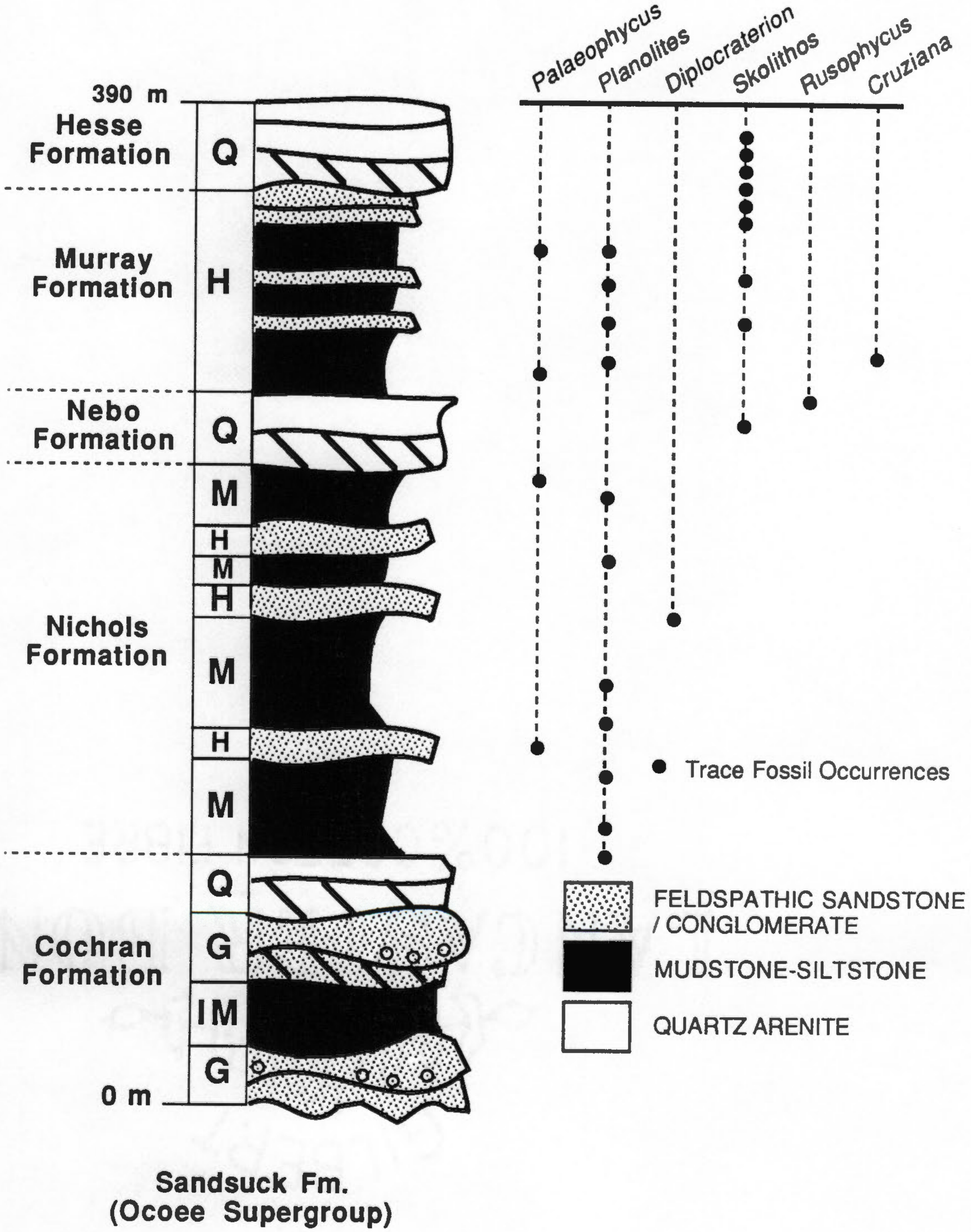
FIG. 2-6. - Summary of trace fossil distribution in the Chilhowee Group at Chilhowee Mountain section (Locality 2 in Figure 1). Q = quartz arenite facies, H = Hummocky facies, S = sandstone facies, G = conglomerate facies. See Figure 2-4 for key to stratification symbols.


380 m
Hesse Formation
Q
Murray Formation
M
Nebo Formation
Q
H
S
H
Nichols Formation
M
Q
S
M
Cochran Formation
Q
G
0 m
faulted
Sandsuck Fm. (Ocoee Supergroup)
Great Smoky Fault
Skolithos
Planolites
Rusophycus
Cruziana
Trace Fossil Occurrences
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE

were observed in the Cochran Formation (Walker and others, 1988). The lowest stratigraphic occurrence of *Skolithos* is in a sandstone body of inner shelf origin that is interbedded with shale of the the Nichols Formation (Fig. 2-6). About 10 m above the first occurrence of *Skolithos* are abundant *Planolites*, which occur in association with thin-bedded tempestites and interbedded siltstone deposits in the upper Nichols Formation (Walker and others, 1988). *Skolithos* become increasingly abundant in the overlying Nebo and Hesse Formations, and *Planolites* and *Paleophycus?* are very abundant in the Murray Formation (Fig. 2-6). *Rusophycus* and *Cruziana*, although rare, appear first in storm shelf deposits of the uppermost Nebo and overlying Murray Formations (Walker and others, 1988). No exposures of the Helenmode were available for examination in this vicinity.

Bean Mountain. The Chilhowee Group stratigraphy at this locality in southeastern Tennessee (Fig. 2-1), closely resembles that observed at Chilhowee Mountain (Fig. 2-2). The precise nature of the contact between the Chilhowee Group and the underlying Sandsuck Formation of the Walden Creek Group is poorly understood. Examination of exposures at this locality yielded no sedimentologic or petrologic evidence for the interpretation of the Sandsuck-Cochran contact as being disconformable, as proposed by King (1964). The lack of positive evidence of disconformity in this area results in its interpretation as conformable, in agreement with the previous interpretation of Neuman and Nelson (1965). This relationship is different to the northeast in the Hot Springs window, North Carolina, where basal conglomerates of the Unicoi Formation contain clasts identical in appearance to lithologies of the immediately underlying Sandsuck Formation (Walker, 1990; see Chapter 5 for discussion). No trace fossils were observed in the Cochran Formation (Fig. 2-7). The stratigraphically lowest traces are *Planolites*, followed slightly higher in the section by *Paleophycus*. Both traces occur in the basal part of the Nichols Formation within shelf tempestite sequences (Fig. 2-7; Skelly, 1987). *Diplocraterion* appears higher in the section, within more proximal tempestite sequences of the upper Nichols Formation. *Skolithos* occurs in the overlying shoreface to inner shelf strata of the Nebo and Hesse Formations (Skelly, 1987). *Rusophycus* and *Cruziana* first appear preserved on the bases of tempestite beds of the lower and middle Murray Formation (Fig. 2-7).

FIG. 2-7. - Summary of trace fossil distribution in the Chilhowee Group at Bean Mountain section (Locality 1 in Figure 1). Q = quartz arenite facies, H = Hummocky facies, S = sandstone facies, G = conglomerate facies. See Figure 2-4 for key to stratification symbols. Data are from Skelly (1987).


Palaeophycus
Planolites
Diplocraterion
Skolithos
Rusophycus
Cruziana
390 m
Hesse Formation
Q
Murray Formation
H
Nebo Formation
Q
M
H
M
H
Nichols Formation
M
H
M
Q
Cochran Formation
G
IM
G
0 m
Sandsuck Fm. (Ocoee Supergroup)
Trace Fossil Occurrences
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE

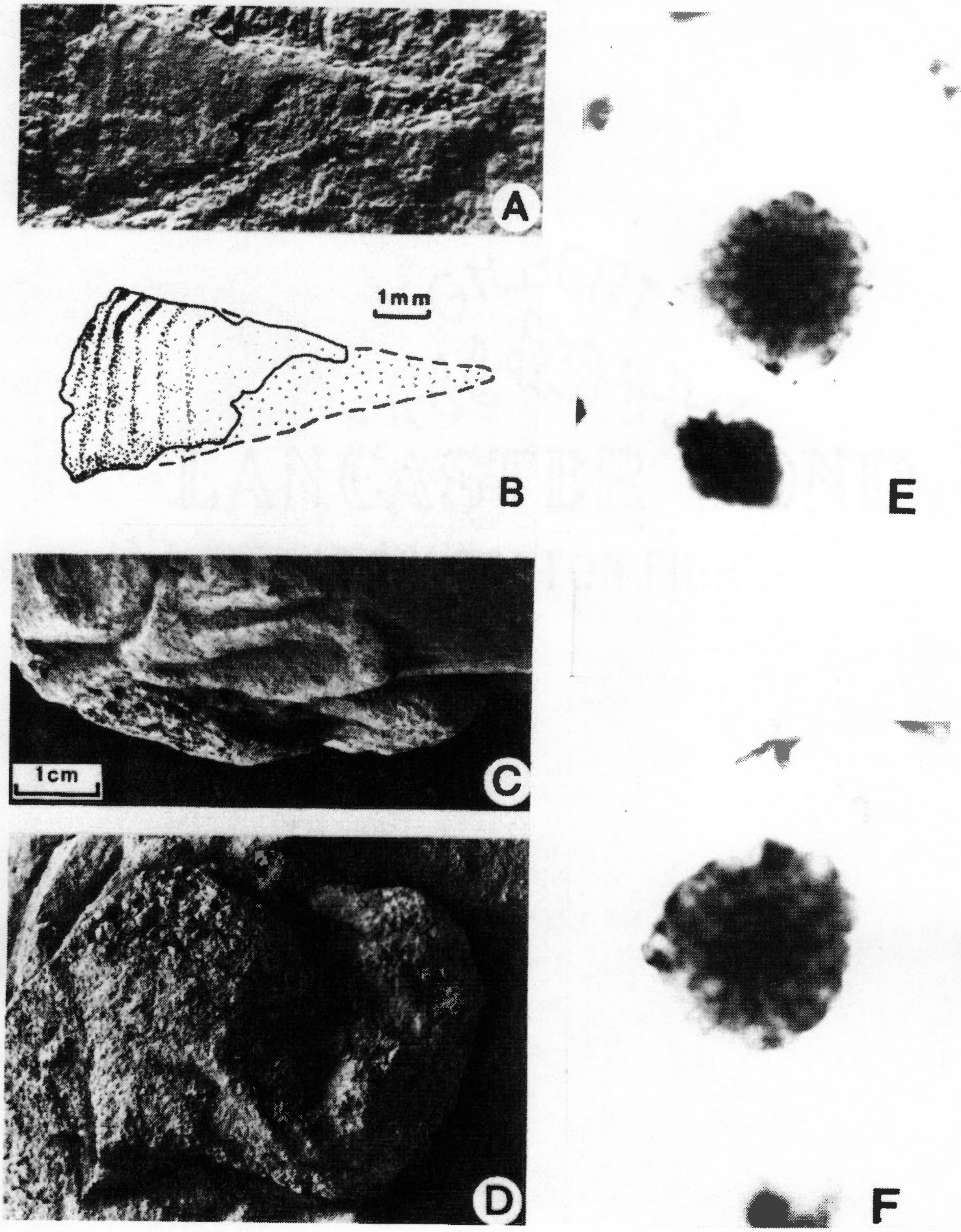
Ocoee Supergroup. Detailed sedimentological study of Ocoee Supergroup sequences were not conducted as part of this study. The Wilhite and the overlying Sandsuck Formations of the Walden Creek Group (Fig. 2-3) were examined without success for trace fossils. No references in the published literature report occurrences of trace fossils in the Ocoee Supergroup, and these rocks are regarded herein as devoid of traces.

Body Fossil Distribution

Chilhowee Group. Despite extensive examination of all three localities, no body fossils have been discovered within the Chilhowee Group. However, body fossils (both macro- and microfauna) have been reported by previous researchers. Walcott (1890; 1891) and Keith (1895) reported the inarticulate brachiopod *Obolella* and the trilobite *Olenellus* from the Murray Shale but, unfortunately did not provide locality and stratigraphic information for their collections; ostracodes and hyolith? were also reported by these authors. Resser (1938) later described the taxonomy of an early ostracode *Indianites tennesseensis* (= *Indiana tennesseensis*) that was apparently collected earlier by Walcott and Keith. Laurence and Palmer (1963) recollected and redescribed *Indiana tennesseensis* from the lower part of the Murray Shale at Murray Gap, Chilhowee Mountain (Figs. 2-1, 2-2, 2-6), and concluded that the Murray Shale is most certainly Lower Cambrian, whereas those stratigraphic units beneath the Murray were considered to be questionable Lower Cambrian. Acritarchs collected and described by Wood and Clendening (1982) at this same locality in the Murray Shale appear to reinforce Laurence and Palmer's (1963) earlier determination of a Lower Cambrian (Atdabanian-equivalent) stage assignment. In much of the southern Appalachians the Chilhowee Group is overlain conformably by carbonate lithologies of the Shady Formation. The Shady Formation in Alabama has yielded archaeocyathids indicative of late Placentian-equivalent deposition (Bearce and McKinney, 1977; McKinney and others, 1988; Tull and others, 1988).

Ocoee Supergroup. Acritarchs collected and described by Knoll and Keller (1979) from throughout the Walden Creek Group indicate a Late Proterozoic (Vendian) age for these strata (Fig. 2-8). Carbonate lithologies exposed within the Wilhite Formation apparently record the existence of a carbonate shelf environment within an

FIG. 2-8. - Fossil discoveries pertinent to the age constraints on the Chilhowee Group in the southern Appalachians. Photographed specimens whitened with ammonium chloride sublimate. 8a and 8b are a photo and line drawing (respectively) of small phosphatic fossil tentatively identified as a hyolith? by Simpson and Sundberg (1987). 8c and 8d are photos of a lobe-shaped hyporelief tentatively identified as the arthropod trace *Rusophycus* by Simpson and Sundberg (1987). 8e and 8f are photomicrographs of Vendian acritarchs from the Shields Formation (uppermost Ocoee Supergroup) identified as *Spaerocongregus (= Bavlinella) faveolatum* by Knoll and Keller (1979). Photos provided by E. Simpson, photomicrographs provided by A. Knoll.

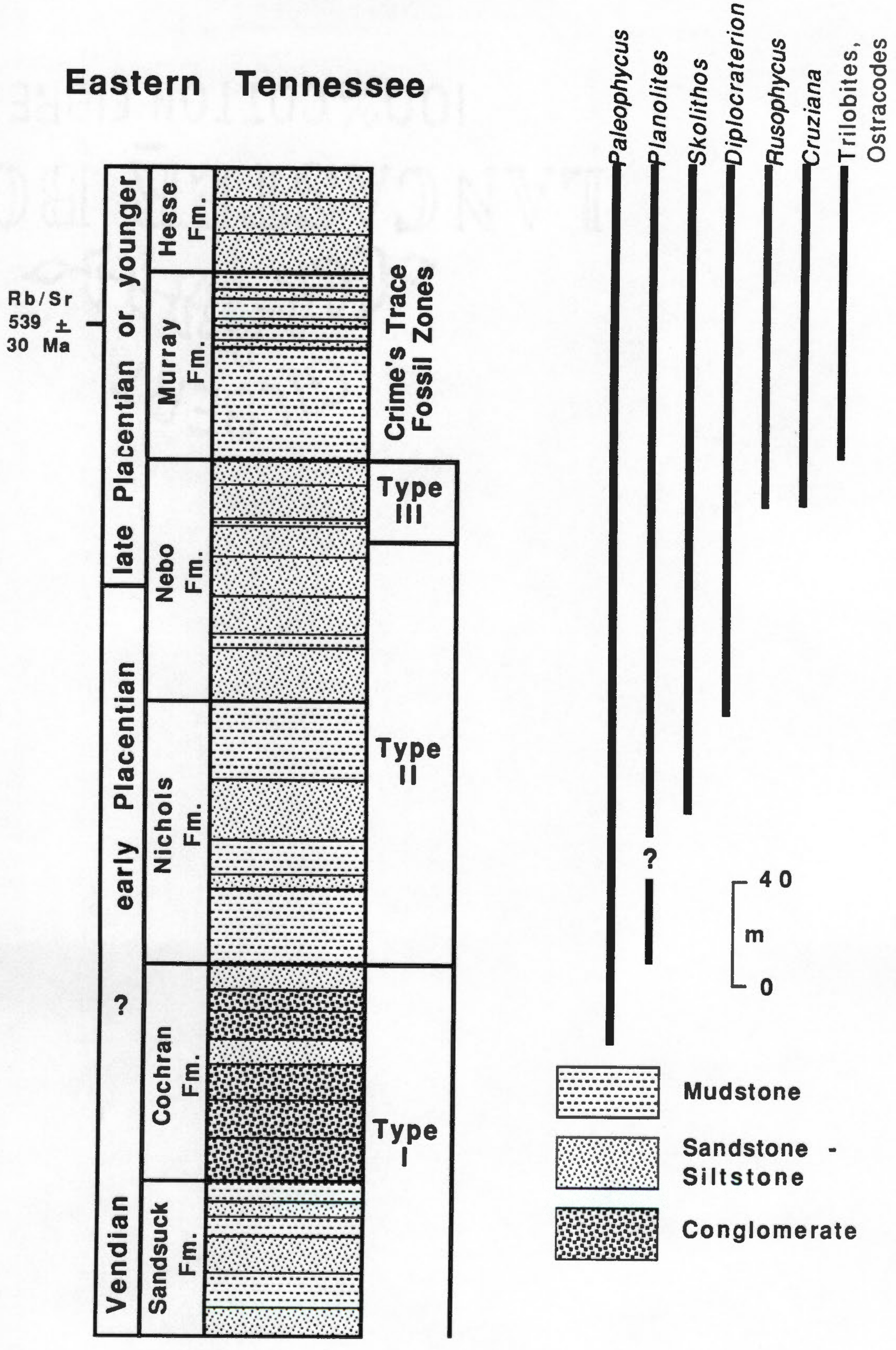

A
1mm
B
1cm
C
D
E
F

otherwise terrigenous-dominated setting (Fig. 2-4; Hanselman and others, 1974). Recent reports of middle Paleozoic body fossil discovered within strata of the Blue Ridge of Tennessee (Unrug, 1990) have yet to be substantiated. These reports, if verified, indicate that strata previously mapped as Walden Creek Group may be Paleozoic in age and the stratigraphic and structural relationships in the area may be more complex than previously thought. Further conclusions based on these early reports of body fossils would premature.

Composite Stratigraphic Section

A composite stratigraphic section that employs all the available trace and body fossil data relevant to determination of the Precambrian-Cambrian boundary in the southern Appalachians is summarized in Figure 2-9. Body fossils constrain the Wilhite Formation (Ocoee Supergroup) as Vendian (upper Precambrian), and the Murray Shale and higher units of the Chilhowee Group as Atdabanian-equivalent or younger (Lower Cambrian). Crimes (1987) recently suggested that trace fossils can be used to assist in boundary assignments in cases where diagnostic body fossils are lacking. Ichnogenera with short time ranges, as well as the first appearances of those with extended stratigraphic ranges are used for correlation. Crimes (1987) described three zones that occur beneath the first trilobite body fossils and include: Zone 1 - (Upper Vendian) is characterized by a low diversity assemblage characterized by simple subhorizontal to vertical burrows that include many ichnogenera which range throughout the Phanerozoic (e.g., *Planolites, Gordia,Neonereites, Skolithos*); Zone 2 - (lower Tommotian-equivalent) is characterized by a more diverse assemblage of traces that include the first appearances of *Bergaueria, Phycodes*, and *Teichichnus*; and Zone 3 - (upper Tommotian-equivalent to lower Atdabanian-equivalent) is characterized by an assemblage that displays the greatest diversity and include the first appearance of several ichnogenera (e.g., *Astropolichnus, Plagiogmus*, and *Taphrhelminthopsis circularis*) and several long-ranging forms such as *Cruziana*, and *Rusophycus* and *Diplocretarion* (Crimes, 1987; Narbonne and others, 1987). Comparison of the reported occurrences of these three assemblages with occurrences of small shelly fossil assemblages (Bengston and Fletcher, 1983; Crimes and Anderson, 1985) recognizable in strata exposed on the Burin Peninsula, Newfoundland, led Narbonne and others (1987) to suggest the following age

FIG. 2-9. - Composite section showing trace and body fossil distributions plotted against a graphic log for the Chilhowee Group of East Tennessee. The Precambrian (Vendian) and Cambrian (Placentian-equivalent) age assignments based on an integrated approach (discussed in text) utilizing trace and body fossils.



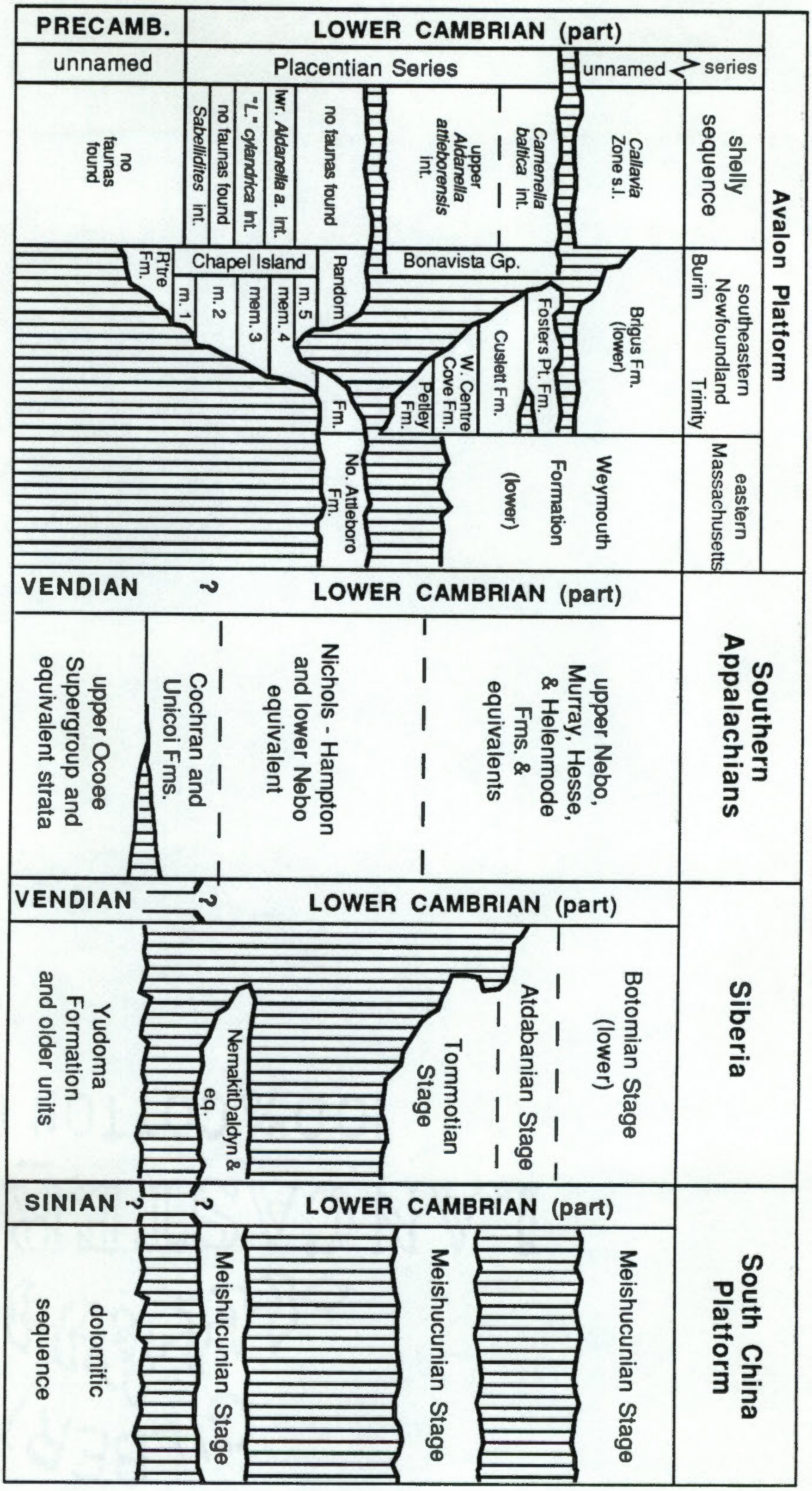
Eastern Tennessee
Rb/Sr
539 ±
30 Ma
Vendian
?
early Placentian
late Placentian or younger
Sandsuck Fm.
Cochran Fm.
Nichols Fm.
Nebo Fm.
Murray Fm.
Hesse Fm.
Type I
Type II
Type III
Crime's Trace Fossil Zones
Paleophycus
Planolites
Skolithos
Diplocraterion
Rusophycus
Cruziana
Trilobites, Ostracodes
?
40
m
0
Mudstone
Sandstone - Siltstone
Conglomerate

re-assignments: upper half of Zone 1 (*Harlaniella podolica* Zone of Narbonne and others, 1987) - late Precambrian (Vendian); Zone 2 (*Phycode pedum* Zone of Narbonne and others, 1987) - earliest Placentian-equivalent (pre-Tommotian-equivalent); and Zone 3 - (*Rusophycus avalonensis* Zone of Narbonne and others, 1987) - late Placentian-equivalent (lower Tommotian-equivalent to upper Atdabanian-equivalent; Fig. 2-10).

Based on similar criteria, three biostratigraphic zones can be recognized in the Chilhowee Group with respect to first occurrences and diversity of trace fossils: Zone 1 - latest Precambrian (Vendian?), includes *Arenicolites, Planolites* and *Skolithos* ; Zone 2 - lower Placentian-equivalent (pre-Tommotian-equivalent), no diagnostic ichnogenera observed in the Chilhowee Group; Zone 3 - late Placentian-equivalent (lower Tommotian-equivalent to upper Atdabanian-equivalent) includes *Cruziana, Diplocraterion* and *Rusophycus*. *Palaeophycus* traces are apparently not age-diagnostic (Häntzschel, 1975). On the basis of our observations in eastern Tennessee, we would assign a late Vendian to early Placentian-equivalent age to the Cochran, Nichols and Nebo Formations, and a late Placentian-equivalent or younger age to the Murray, Hesse and Helenmode Formations Figs. 2-9 and 2-10).

Simpson and Sundberg (1987) assigned a late Vendian? to late Tommotian-equivalent age to the Unicoi Formation (Cochran Formation equivalent) in Virginia (Fig. 2-2). This age assignment was based on the occurrence within the Unicoi Formation of a single lobe-shaped hyporelief identified as *Rusophycus*. Field examination of this horizon (by SGD) indicates that the identification of this feature as *Rusophycus*, or even as a biogenic trace, is not unequivocal (Fig. 2-8). Furthermore, their report of a small phosphatic? conical fossil described as similar in ornamentation, size, and shape to the hyolithid *Tuojdachithes? biconvexus* (as illustrated by Brasier, 1984; his Fig. 3r and 3s) prompted them to assign a tentative age of late Tommotian or Atdabanian (= *Fallotaspis* biozone) to the overlying the Hampton Formation (Fig. 2-2). Simpson and Sundberg's specimen (Fig. 2-8), however differs substantially from that illustrated by Brasier in longitudinal profile, ornamentation, and mineral composition (phosphatic versus calcareous) precluding a reliable taxonomic assignment. If the Hampton Formation of southwestern Virginia precisely correlates with the Nichols Shale of Tennessee, then the occurrence of the hyolith? reported by Simpson and Sundberg (1987) in the Hampton would require that at least some part of the Nichols (as well as *all*

FIG. 2-10. - Comparison of age assignments for the Chilhowee Group with Placentian-equivalent strata of the Avalon Platform, Siberia, and South China Platform. Modified from Landing (1988).


PRECAMB.
LOWER CAMBRIAN (part)
unnamed
Placentian Series
unnamed
series
Avalon Platform
shelly sequence
southeastern Newfoundland
Burin
Trinity
eastern Massachusetts
Callavia Zone s.l.
Camenella baltica int.
upper Aldanella attleborensis int.
no faunas found
lwr. Aldanella a. int.
"L." cylandrica int.
no faunas found
Sabellidites int.
no faunas found
Brigus Fm. (lower)
Bonavista Gp.
Fosters Pt. Fm.
Cuslett Fm.
W. Centre Cove Fm.
Petley Fm.
Random Fm.
Chapel Island
m. 5
mem. 4
mem. 3
m. 2
m. 1
R'tre Fm.
Weymouth Formation (lower)
No. Attleboro Fm.
VENDIAN
LOWER CAMBRIAN (part)
Southern Appalachians
upper Nebo, Murray, Hesse, & Helenmode Fms. & equivalents
Nichols - Hampton and lower Nebo equivalent
Cochran and Unicoi Fms.
upper Ocoee Supergroup and equivalent strata
VENDIAN
LOWER CAMBRIAN (part)
Siberia
Botomian Stage (lower)
Atdabanian Stage
Tommotian Stage
NemakitDaldyn & eq.
Yudoma Formation and older units
SINIAN
LOWER CAMBRIAN (part)
South China Platform
Meishucunian Stage
Meishucunian Stage
Meishucunian Stage
dolomitic sequence

of the overlying Nebo Sandstone) must be early Atdabanian-equivalent in age (as apposed to early Tommotian-equivalent as proposed herein). This apparent discrepancy in the assigned ages of the coeval Cochran and Unicoi formation as well as the overlying Nichols and Hampton Formations is difficult to resolve. In light of the inconclusive nature of the identification of these fossils, and because we cannot rule out the possibility of at least some diachronism of the various Chilhowee lithologic units, a more conservative age assignment is proposed here (Figs. 2-9 and 2-10).

Tectono-stratigraphic Effects on the Nature of the Precambrian-Cambrian Boundary

When the nature of the Precambrian-Cambrian boundary from these locations is compared with other well studied localities (such as the Chapel Island Formation of the Burin Peninsula, Newfoundland; Narbonne and others, 1987), it becomes apparent that there is a strong sedimentologic and environmental control on the types of fossils (trace or body) produced and preserved in any given area. The depositional environments represented by the strata of the Burin Peninsula differ dramatically from those represented by the basal Chilhowee Group of the southern Appalachians, with the latter representing fluvial siliciclastic deposition and the former representing marine siliciclastic and carbonate deposition. The contrasting Late Proterozoic to Early Cambrian environmental settings (of the Burin Peninsula and the southern Appalachians) produced a unique suite of fossils (body and trace) which indicate that: 1) fluvial siliciclastic settings are typically devoid of trace and body fossils; 2) marine siliciclastic settings are typically dominated by trace fossils; and 3) marine carbonate settings are typically dominated by body fossils (Stanley, 1976; Narbonne and others, 1987).

Because many Upper Proterozoic to Lower Cambrian sequences world-wide were apparently deposited in response to a major continental break-up (Bond and others, 1984) there is a strong tectonic control on the distribution of paleoenvironments through time and space and therefore an indirect control on the nature of the Precambrian-Cambrian boundary. Study of the rift to passive-margin transition in a number of modern and ancient examples has resulted in the recognition of a characteristic sequence of successive depositional settings as follows: 1) alluvial fan and fluvial, 2) incipient siliciclastic dominated marine shelf, and 3) stabilized, carbonate dominated marine shelf, in appropriate latitudes. The biotic and lithologic record of the Precambrian-Cambrian boundary at any continental margin location may then reflect the degree to which break-up had progressed.

CONSTRAINTS ON THE POSITION OF THE PRECAMBRIAN-CAMBRIAN BOUNDARY IN THE SOUTHERN APPALACHIANS: OVERVIEW AND PROBLEMS

There appears to be a strong facies control on the distribution of trace and body fossils in the Chilhowee Group. In fact, these problems may ultimately prove insurmountable:

(1) The basal deposits of the Chilhowee Group are largely braided fluvial/alluvial in origin (Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988; Simpson and Eriksson, 1989) and very coarse-grained. Such facies are not conducive to the recovery of either trace or body fossils. Dating the Cochran-Unicoi interval is especially critical because it is underlain by the Ocoee Supergroup with its Vendian acritarchs (Knoll and Keller, 1979, Fig. 2-2, 2-3, and 2-8), and is overlain by younger Chilhowee formations such as the Murray Shale, which contain reliable indicators of an Atdabanian-equivalent or younger age (e.g., Laurence and Palmer, 1963; Wood and Clendening, 1982). Hence, a part of the lower Placentian-equivalent (pre-Tommotian-equivalent) stage may be represented by a thick sequence of fluvial or alluvial deposits (Figs. 2-9 and 2-10).

(2) The Chilhowee Group is completely devoid of any carbonate (limestone or dolostone) deposits. Therefore, the possibility of extracting shelly microfossils characteristic of the Placentian-equivalent stage appears remote. Only trace fossils offer much hope of allowing for a more refined biostratigraphic zonation of the Precambrian-Cambrian boundary in the southern Appalachians, and even they have limitations (Crimes, 1987). Trace fossil assemblages are facies dependent, therefore care must be taken to compare strata representing similar depositional settings when attempting to draw conclusions regarding trace fossil diversity. Further attempts to determine the age of the fine-grained marine deposits of the Chilhowee Group would be enhanced by a systematic attempt to recover and identify acritarchs from these intervals.

(3) The timing of continental breakup may also prove critical. The occurrence of synrift strata of the Unicoi Formation in northeastern Tennessee and southern Virginia

suggests that the southern Appalachian margin may have been too youthful and terrigenous clastic-dominated at the critical time intervals of approximately 590 to 570 Ma to have accumulated a stratigraphic (and associated fossil) record that can be dated with precision.

SUMMARY AND CONCLUSIONS

The Chilhowee Group represents a fluvial-to-marine, late synrift to early drift succession of probable late Precambrian (Vendian) to Early Cambrian (Placentian-equivalent or younger) age. Age constraints are provided by: (1) the occurrence of Vendian acritarchs in the subjacent Sandsuck, Wilhite, and Shields Formations of the Ocoee Supergroup, (2) the first occurrence of *Palaeophycus* traces in the basal Cochran and Unicoi Formations, (3) the first occurrences of *Skolithos* and *Planolites* traces in the overlying Nichols and Hampton Formations, (4) the abundances of well-developed arthropod (*Rusophycus*, *Cruziana*) as well as other diagnostic traces (*Diplocraterion*) in the uppermost Nebo and overlying Murray Formations, (5) the re-calculated age of 539 $\pm$ 30 Ma for the Murray Formation (based Rb-Sr ratios as determined from glauconite), and (6) reported occurrences (in the literature) of upper Placentian-equivalent or younger (Atdabanian-equivalent or younger) body fossils recovered from the Murray Shale, which include trilobites, ostracodes, inarticulate brachiopods, hyolithids and acritarchs. Based on the recent suggestions of Crimes (1987) that trace fossils can be used to assist in correlating the Precambrian-Cambrian boundary interval in stratigraphic sequences in which diagnostic body fossils are lacking, a late Vendian? to early Placentian-equivalent (sub-Tommotian-equivalent) age is assigned to the Cochran and Unicoi Formations. An early late Placentian-equivalent (early to late Tommotian-equivalent) age is the assigned to the Nichols and Hampton Formations and the lower and middle Nebo Formation . Finally, a late Placentian-equivalent or younger (Atdabanian-equivalent or younger) age is assigned to the upper Nebo, Murray, Hesse and Helenmode Formations. The Precambrian-Cambrian boundary is probably located somewhere within the uppermost portion of Cochran-Unicoi interval (Figs. 2-8 and 2-9). Unfortunately, this sequence is dominated by coarse-grained braided fluvial facies, and so it may ultimately prove impossible to locate the boundary more precisely, because of a lack of marine facies in this critical time interval.

If the Unicoi Formation of southwestern Virginia precisely correlates (in-age) with the Cochran-Unicoi interval in Tennessee, then the possible occurrence of *Rusophycus* in the middle Unicoi Formation of southwestern Virginia reported by Simpson and Sundberg (1987) suggests that the upper Cochran-Unicoi interval in Tennessee is late Placentian-equivalent (Tommotian-equivalent) age. Similarly, if the Hampton Formation of southwestern Virginia precisely correlates (in-age) with the Nichols-Hampton interval in Tennessee, then the occurrence of a hyolith? in the lower Hampton Formation reported by Simpson and Sundberg (1987) would indicate that the Nichols-Hampton, as well as *all* of the overlying Nebo Formation, is of latest Placentian-equivalent (late Tommotian-equivalent to early Atdabanian-equivalent) age. More conservative stage assignments have been proposed here because of the probability of at least some diachronism (on a regional basis) between Chilhowee formational units and the equivocal nature of the Virginia fossil discoveries. The stage assignments proposed here are therefore subject to possible revision, if and when more unequivocal body or trace fossil data become available.

CHAPTER 3

THE CHILHOWEE GROUP OF EAST TENNESSEE: SEDIMENTOLOGY OF THE LOWER CAMBRIAN FLUVIAL-TO-MARINE TRANSITION

INTRODUCTION

The Chilhowee Group (uppermost Proterozoic to Lower Cambrian; see Chapter 2 for more discussion) is a 600-1200 m thick terrigenous clastic sequence of interbedded feldspathic and lithic conglomerate, feldspathic and quartz arenite, siltstone, and shale that crops out in narrow belts along the western margin of the Blue Ridge province and immediately adjacent thrust belts of the Valley and Ridge province (Schwab, 1972; Whisonant, 1974; Mack, 1980). The northeast-southwest trending outcrop extends along strike from Alabama to Vermont and varies in extent across strike.

Various formations comprise the Chilhowee Group throughout its extent. Even within the limited portion of the outcrop belt exposed in the southern Appalachians, the stratigraphy differs substantially (Figs. 3-1 and 3-2). Previous studies dealing with the Chilhowee Group stratigraphy and petrology have tended to treat the Chilhowee as a "layer-cake" stratigraphic sequence (Schwab, 1972; Whisonant, 1974). This paper will address by example, the facies variability within the Chilhowee Group of southeast (Skelly, 1987; Skelly and Driese, 1987), central, and northeast Tennessee (Cudzil, 1985; Cudzil and Driese, 1987).

REGIONAL SETTING

The Chilhowee Group of East Tennessee is exposed along the western margin of the Blue Ridge physiographic province. The exposures of Chilhowee Group strata occur primarily within erosional remnants of the Great Smoky thrust complex and related thrust sheets of the Blue Ridge thrust system (Hatcher, 1989). The thrust geometry of the Great Smoky complex is characterized by extensive duplex systems and the relationship between individual thrust sheets throughout the area is

FIG. 3-1. - Outcrop locations for the Chilhowee Group and regional geology of East Tennessee. Localities discussed in this paper are: BM) Bean Mountain (from Skelly, 1987); CM) Chilhowee Mountain, VF) Valley Forge from Cudzil and Driese, 1987); I-40) along Interstate 40 south of Newport, Tennessee; and EM) English Mountain.

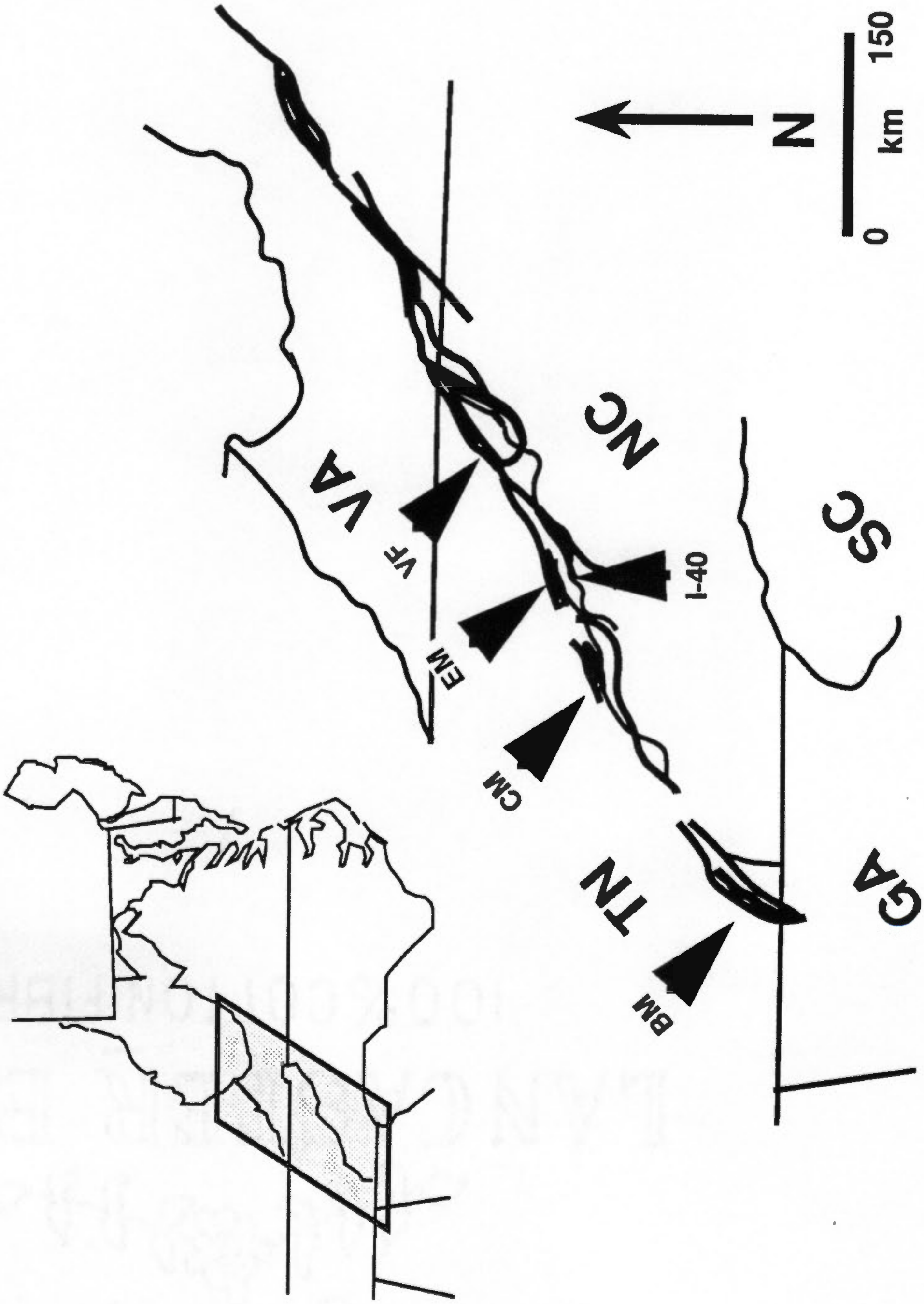

VA
NC
SC
TN
GA
VF
EM
CM
BM
I-40
N
0
km
150

FIG. 3-2. - Chilhowee Group stratigraphy, southern Appalachians. Modified from (Mack, 1980; Cudzil and Driese, 1987).

<table>
<tr><th>AGE</th><th colspan="2">North Georgia and Alabama</th><th colspan="2">Southeastern Tennessee</th><th colspan="2">Hot Springs window, North Carolina</th><th colspan="2">Northeastern Tennessee</th><th>Southwestern Virginia</th><th>Northwestern Virginia</th></tr>
<tr><td rowspan="7">EARLY CAMBRIAN</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td>Shady Dolomite</td><td>Tomstown Dolomite</td></tr>
<tr><td rowspan="6">CHILHOWEE GROUP</td><td rowspan="2">Weisner Formation</td><td colspan="2">Helenmode Formation</td><td rowspan="4">Erwin Formation</td><td>Helenmode Member</td><td rowspan="4">Erwin Formation</td><td>Helenmode Member</td><td rowspan="4">Erwin Formation</td><td rowspan="4">Antietam Quartzite</td></tr>
<tr><td colspan="2">Hesse Quartzite</td><td>Hesse Quartzite Member</td><td>Hesse Quartzite Member</td></tr>
<tr><td rowspan="2">Wilson Ridge Formation</td><td colspan="2">Murray Shale</td><td>Murray Shale Member</td><td>Murray Shale Member</td></tr>
<tr><td colspan="2">Nebo Quartzite</td><td>Nebo Quartzite Member</td><td>Nebo Quartzite Member</td></tr>
<tr><td>Nichols Shale</td><td colspan="2">Nichols Shale</td><td colspan="2">Hampton Shale</td><td colspan="2">Hampton Shale</td><td>Hampton Shale</td><td>Harpers Formation</td></tr>
<tr><td>Cochran Formation</td><td colspan="2">Cochran Formation</td><td colspan="2">Unicoi Formation</td><td colspan="2">Unicoi Formation</td><td>Unicoi Formation</td><td>Weaverton Quartzite
Loudon Formation</td></tr>
<tr><td>?- PROTEROZOIC</td><td colspan="2">base of section always faulted out</td><td>Ocoee Supergroup</td><td>Sandsuck Formation</td><td>Ocoee Supergroup</td><td>Sandsuck Formation</td><td colspan="2">Mount Rogers Volcanic Group or Grenville basement</td><td>Mount Rogers Volcanic Group</td><td>Catoctin Greenstone or Swift Run Fm. or injection complexes</td></tr>
</table>

the focus of much disagreement (Woodward, pers. comm.). Consequently in some areas Chilhowee Group strata occur within both the hanging wall and footwall blocks, with the latter exposed within structural windows (Robert, 1987). The variation in stratigraphic nomenclature along structural strike may then reflect facies trends which deviate from the strike of the Great Smoky thrust surface. This facies variation may be the manifestation of an irregular continental margin and/or variable amounts of tectonic transport along the length of the Great Smoky complex in East Tennessee.

Stratigraphic sections forming the basis of this study are located at Bean Mountain and Chilhowee Mountain both within the the Great Smoky thrust sheet, along Interstate 40 south of Newport, Tennessee within a footwall duplex of the Great Smoky thrust (this duplex has been termed the Denton Duplex by Robert, 1987), and at the Valley Forge locality of the Holston Mountain thrust sheet (Fig. 3-1). In addition extensive filed examination of the Chilhowee Group at English Mountain (within the Great Smoky thrust sheet) was conducted. Due to the limited nature of exposure at that locality no detailed description and measurement was undertaken. The gross thickness of exposed units and their general lithologic nature, however, were noted. While these three thrust sheets (i.e., Great Smoky, Denton Duplex, and Holston) appear to be related (forming the Tennessee portion of the Great Smoky thrust complex), the precise geometric relationship between them still forms the object of much debate (Woodward, N., pers. comm., 1988). Thus, sections exposed in each sheet may represent separate portions of the Chilhowee depositional system and may have experienced differing amounts of tectonic transport. Mapping in the southeast of the English Mountain area by Robert (1987) indicated that in some settings structural relationships can be elucidated. Palinspastic reconstruction of a balanced cross-section which extends from English Mountain southeast through the Denton Duplex indicates that the exposures of the Chilhowee Group at English Mountain were deposited in more distal settings (oceanward) than those observed along Interstate 40 (Fig. 3-3). Consequently, limited structural evidence indicates that the strata possessing the 6-fold stratigraphy characteristic of the Chilhowee Group in southeastern Tennessee (Cochran through Helenmode Formations; Fig. 3-2) may represent more distal sedimentation than strata possessing the 3-fold stratigraphy characteristic of the Chilhowee Group in northeastern Tennessee and southern Virginia (Unicoi through Erwin Formations; Fig. 3-2).

DESCRIPTION AND INTERPRETATION OF FACIES

Six facies were defined based on detailed in-field examination of Chilhowee Group exposures in eastern Tennessee. These facies include: 1) the conglomerate facies, 2) the interlaminated sandstone - mudstone facies, 3) the sandstone facies, 4) the mudstone - siltstone facies, 5) the hummocky facies, and 6) the quartz arenite facies. Some of these facies possess variants described below. The diverse stratigraphic nomenclature applied to the Chilhowee Group of East Tennessee (Fig. 3-2), reflects to some degree the various processes responsible for its deposition. Therefore, the distribution of facies among the various exposures should provide some insight into the relative position of each locality with respect to the paleoshoreline (Table 3-1).

Conglomerate Facies

The conglomerate facies is restricted to the Unicoi-Cochran interval and is commonly associated with the sandstone facies and/or the quartz arenite facies in some areas. It is the most immature, poorly sorted lithology present in the Chilhowee Group. Mineralogically, it is characterized by varying proportions of feldspar, quartz, and/or sedimentary rock fragments. Metamorphic rock fragments and micas are present and depositional matrix is abundant (Fig. 3-4; see Chapter 5 for more discussion). Texturally, this facies is composed of framework components ranging in size from silt to pebbles, with grains subangular to subrounded grains. Trace fossils are rare, although some occurrences of *Palaeophycus* have been observed (Cudzil, 1985; Cudzil and Driese, 1987; see Chapter 2 for more discussion).

The immature nature of this facies is interpreted as representing the general absence of reworking within the depositional environment. Three distinctive sequences of sedimentary structures within the conglomerate facies indicate deposition within a braided stream system (Cudzil and Driese, 1987).

Massive conglomerate variant. This variant is characterized by thick- to very thick-bedded lithic and arkosic conglomerate (for precise definition of terms describing bed thickness and grain size see Appendix A). Beds of this variant are amalgamated and typically thicken and coarsen upsection. At some locations, beds of this facies display a distinct lenticular morphology, which is highlighted by the occurrence of siltstone layers which bound the upper surface. However, this facies is characteristically massive in

FIG. 3-3. - Geologic cross-section constructed from English Mountain southeast through the Denton Duplex. Note the inferred tectonic transport along Great Smoky fault placing the English Mountain locality cratonward of the I-40 locality (Denton Duplex). Mapping and cross-section completed by Robert (1987). Figure modified from Robert (1987).

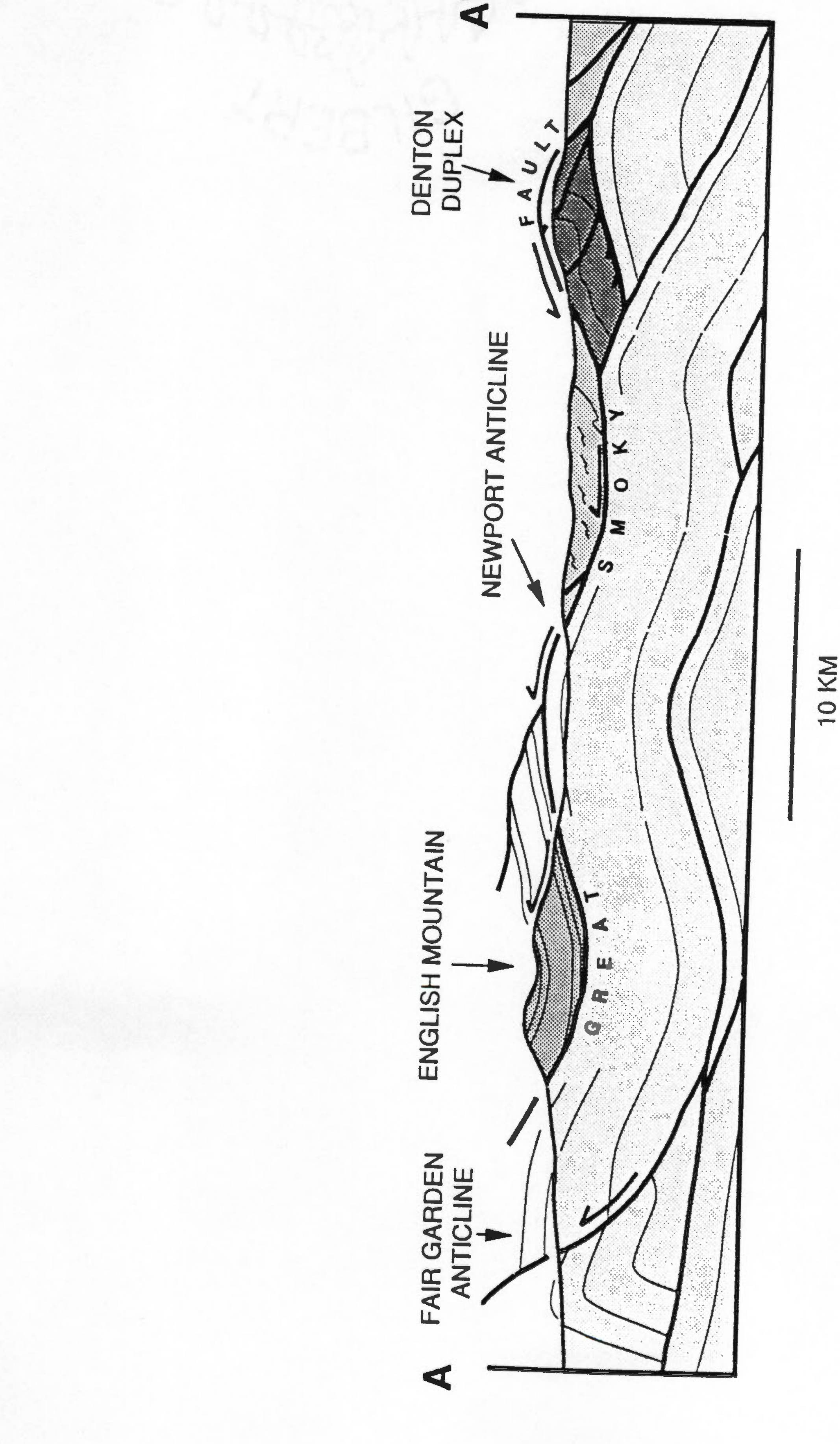
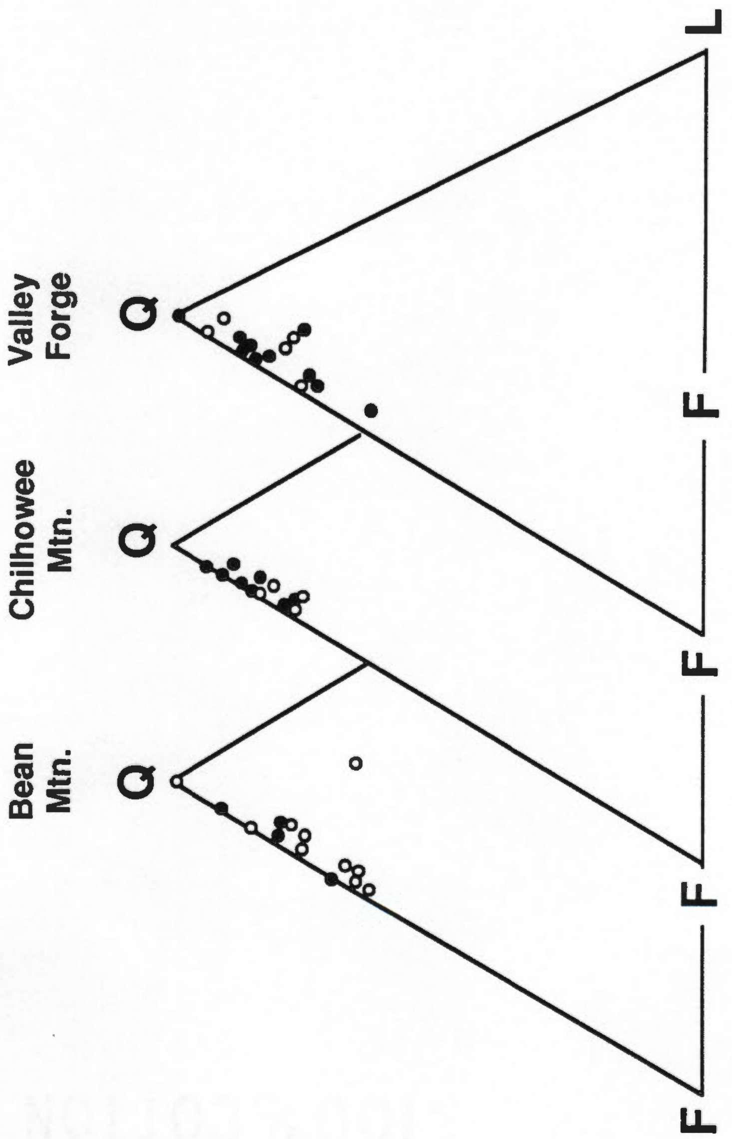

A
FAIR GARDEN ANTICLINE
ENGLISH MOUNTAIN
G R E A T
NEWPORT ANTICLINE
S M O K Y
DENTON DUPLEX
F A U L T
A'
10 KM

TABLE 3-1. - *Facies description, interpretation, and distribution*

FACIES	VARIANTS	DESCRIPTION	PROCESS INTERPRETATION	ENVIRONMENT	REGIONAL DISTRIBUTION Bean Mtn.	Chilhowee Mtn.	Valley Forge
Conglomerate	Massive	planar to lenticular bed geometry, internal stratification absent	upper flow regime	longitudinal channel bars - BRAIDED STREAM	Cochran		Unicoi
	Large-scale cross-stratified	large-scale planar-tabular cross-stratified, erosional base and rippled top	lower flow regime, high flood stage	transverse channel bars - BRAIDED STREAM	Cochran	Cochran	
	Megaripple cross-stratifed	megaripple cross-stratification, clay drape along bedform surface	megaripple migration during flooding, subsequent deposition from suspension	interbar pool - BRAIDED STREAM			Unicoi
	Horizontally laminated sandstone	horizontal laminae, granule laminae, small-scale cross-stratification	upper flow regime, local variations in flow conditions	vertical accretion on flood plain - BRAIDED STREAM	Cochran		Unicoi
Interlaminated Sandstone - Mudstone		horizontally laminated mud- and sandstone, minor cross-stratification at base	deposition from suspension, minor component of lower flow regime sedimentation	lacustrine deposition within braidplain - LACUSTRINE associated with BRAIDED STREAM	Cochran		
Sandstone		interbedded bioturbated and ripple cross-stratified sandstone	suspension deposition, weak currents ripple sand	slack water deposition - SUBTIDAL CHANNELS AND SHOALS			Unicoi, Hampton, Erwin
		large-scale, planar-tabular and trough cross-stratifed, granule lags	erosion and subsequent depostion by ebb-tidal current	deep channel - SUBTIDAL CHANNELS AND SHOALS			Unicoi, Hampton, Erwin
		medium-scale, planar-tabular and trough cross-stratifed, rare asymmetrical ripples	deposition by ebb-tidal currents above wave-base	shallow channel or shoal - SUBTIDAL CHANNELS AND SHOALS			Unicoi, Hampton, Erwin
Mudstone-Siltstone		variably cross-stratified, and bioturbated silt- and mudstone. Thin hummocky, sandstone beds and glauconite throughout.	fair-weather deposition of finer fraction, during sediment starved shelf conditions, with storm emplaced sandstone beds	fairweather deposition below normal wave base - OUTER SHELF	Nichols, Murray	Nichols, Murray	
Hummocky		interbedded hummocky sandstone and bioturbated siltstone, locally glauconitic, symmetrical ripple forms with unidirectional x-laminae, Cruziana ichnofacies	deposition between storm and fair-weather wave base; sands deposited by storms, fairweather suspension deposition and recolonization of substrate by infauna	deposition between sand ridges or at the end of a storm/tidal current transport path - STORM DOMINATED SHELF	Nichols, Murray	Nichols,Nebo, Murray	Erwin
Quartz arenite	Lower	low-angle cross-stratification, large-scale planar-tabular cross-stratification, broad shallow scours, symmetrical ripples	intense reworking of fluvial sediment, swash and backwash important	subtidal sand ridge - STORM DOMINATED SHELF	Cochran	Cochran	Unicoi
	Upper	large-scale planar-tabular cross-stratification, erosional lower surface, granule lag at top, sandstone bodies 1-9m thick, No fines	deposition and reworking by tidally enhanced storm currents	ridge and runnel - STORM DOMINATED SHELF	Nebo, Hesse	Nebo, Hesse	Erwin

FIG. 3-4. - Relative abundance of monocrystalline quartz (Q), feldspar (F) and detrital lithic grains (L) as determined by point counting medium- to coarse-grained sandstones. Open circles represent samples taken from below the inferred fluvial-to-marine transition and therefore are interpreted as being fluvial in nature. Solid circles represent samples taken from above the inferred fluvial-to-marine transition and therefore may include both marine and/or fluvial deposits.


Bean Mtn.
Chilhowee Mtn.
Valley Forge
Q
Q
Q
F
F
F
F
L

appearance, with the nature of the internal stratification indeterminable (Skelly, 1987; Walker and others, 1988).

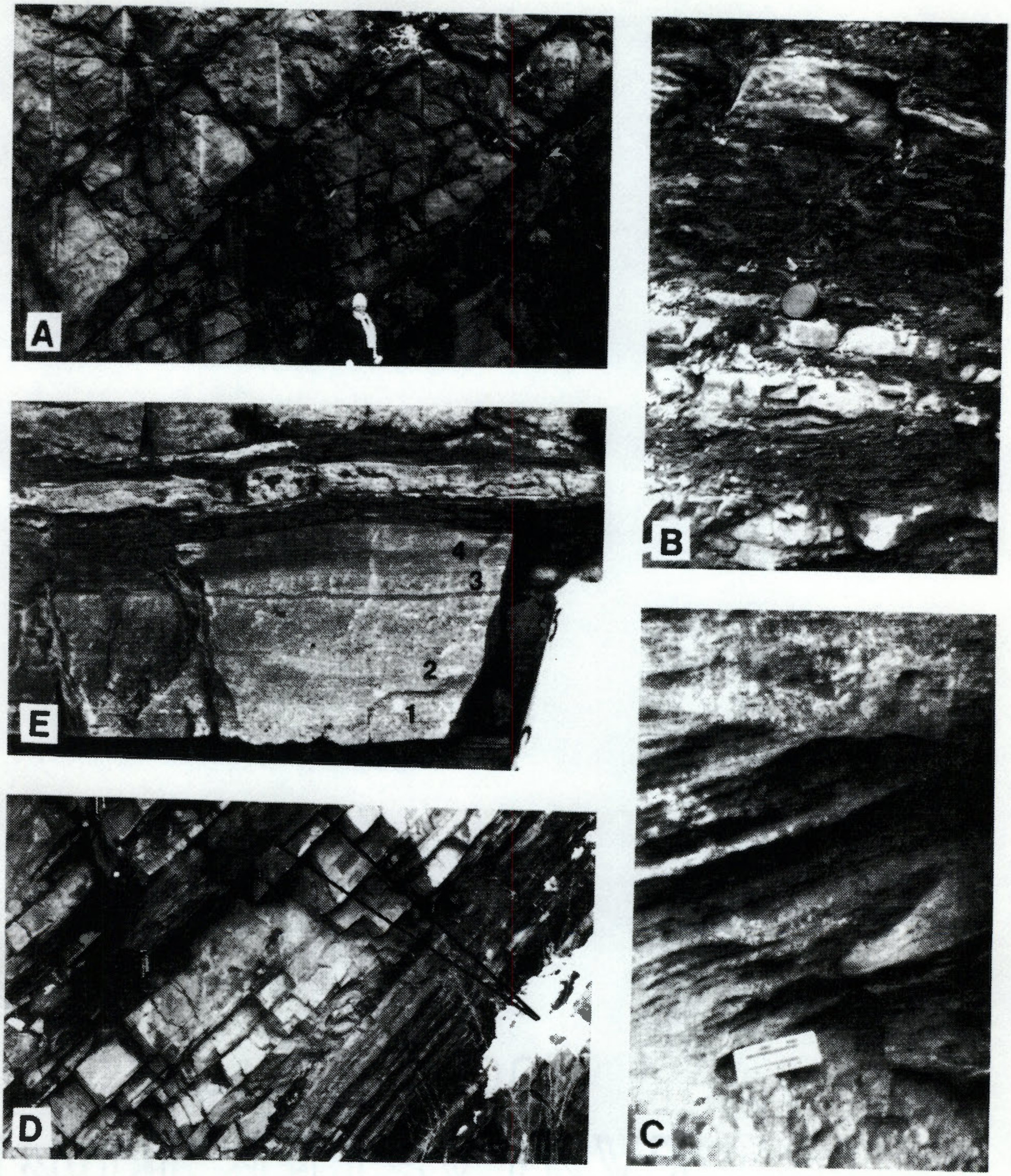
Massive, crudely bedded accumulations of gravel are recognized in modern braided stream systems, and tend to grow by vertical accretion (Miall, 1977, 1978, 1982). Because these build-ups are typically elongate in a direction parallel to flow they have been termed longitudinal bars (Smith, 1970, 1974; Miall, 1977, 1978; Boothroyd and Nummedal, 1978). As described by Smith (1970), longitudinal bars differ from transverse bars in that the former are coarser-grained and thus tend to be located in the more proximal reaches of the braided fluvial system. This apparent spatial relationship may represent variations in the relative fluid and sediment discharge within the channel at the time of deposition (Hein and Walker, 1977). Such variation through time may result in the formation of both bar types within the same general area, thus the association of the massive conglomerate variant with the large-scale cross-stratified variant within the basal Chilhowee Group is not unexpected (Hein and Walker, 1977; Skelly, 1987; Walker, and others, 1988).

Large-scale cross-stratified conglomerate variant. Planar-tabular cross-sets that range in thickness from 0.5 to 3.0 m characterize this variant (Fig. 3-5A). The base of each set appears to be erosional in nature and is horizontal. The 0.3 m thick bottom-set contains crude, thin laminations of silt, sand, granules, and pebbles. The 0.04 to 0.15 m thick foresets are normally graded from pebbles to coarse sand. At some localities, megaripple trains truncate the foresets, and exhibit cross-lamination.

This variant is interpreted as having been deposited by migration of large, transverse channel-bars in a distal reach of a braided stream system. Cross-stratified clast-supported gravel is the dominant lithofacies in distal braided streams, whereas horizontally bedded, imbricate gravels are common in proximal reaches (Rust, 1981). The sharp, flat bases of the foresets are interpreted to represent erosion in front of the channel bar as it migrates during high-flood stage. The poorly-sorted and crudely laminated bottomset indicates deposition of silt- to gravel-sized sediment from suspension as well as from bedload. The steeply-dipping (approximately 25^{o}), graded foresets are characteristic of channel bars which possess active slip faces (Bluck, 1974).

In modern braided rivers, the size of transverse bars varies even within a particular river. In the Tana River of Norway (Collinson, 1978), bars range from 200 to

FIG. 3-5. - Field photographs of facies described from the Chilhowee Group of East Tennessee. Facies shown include: A) **Conglomerate** facies (large-scale variant from the Valley Forge locality) Note: the large-scale cross-bedding enhanced by line drawings. Woman for scale is approximately 1.6 m tall; B) **Mudstone-Siltstone** facies (Chilhowee Mountain locality). Lens cap for scale is 6 cm in diameter; C) **Quartz arenite** facies (upper occurrence; Chilhowee Mountain locality). DNAG scale measures 16.5 cm in the long dimension; D) coarsening upward sequence of the **Hummocky** facies (Valley Forge locality). Sequence identified by line drawing measures 1.5 m in thickness; E) ideal example of the **Hummocky** facies (see text for explanation; Valley Forge locality); Field book in lower right corner for scale. Photos A, E, and D from Cudzil, 1985.


A
B
4
3
2
1
E
D
C

300 m in length, 200 m in width and up to 2 m in height. These bedforms are large enough to generate features similar to the large-scale planar tabular cross-stratification seen in this variant.

Megaripple cross-stratified conglomerate variant. - This variant is typically a pebbly, arkosic lithic wacke which displays medium-scale cross-stratification, interbedded with laminated siltstone. The cross-stratified conglomerate beds have erosional bases and wavey tops, which apparently represent the original megaripple bedforms. The spacing of the megaripples is about 1 m and amplitude is about 0.05 m. Megaripples are commonly overlain by laminated siltstone, which drapes the bedform. The siltstone commonly display discontinuous laminae consisting of very-coarse sand and granules. Individual laminae are commonly only one to two grains thick. The interbedded sequences of siltstone and conglomerate range in thickness from 0.25 to 1.0 m (Cudzil and Driese, 1987).

The close association of the cross-stratified conglomerate with the laminated siltstone in this variant indicates large and rapid fluctuations in flow strength. Deposition probably occurred on top of, and between, transverse channel-bars, where medium-scale coarse-grained bedforms developed with falling flood stage and large bedforms ceased to migrate. During low-water stands, pools developed between large bars and silt settled from suspension and draped the underlying megaripple surface (Cudzil and Driese, 1987). This relationship between bedform type and size and flow stage has been documented by Smith (1970, 1971), Hine and Boothroyd (1978), Miall (1977), and Boothroyd and Nummedal (1978) in many modern systems.

Horizontally laminated sandstone variant. Consisting predominantly of very fine- to fine-grained, feldspathic lithic wacke, this variant commonly possesses siltstone lenses, thin siltstone beds, granule/pebble-filled lenses, granule/pebble laminae and scattered pebbles. The dominant sedimentary structure is horizontal to very low-angle, wavy to even parallel laminations. Accumulations of up to 8 m of monotonous, horizontally laminated sandstone occur. Low-angle erosional surfaces many separate 0.1 to 0.2 m sets of evenly-laminated, fine-grained sandstone.

The typical stratification sequence consists of a basal gravel lens which is commonly cross-stratified, overlain by laminated sandstone. Small-scale trough cross-stratification may cap the sequence. Commonly, however, there is no ordering of the stratification features.

At some occurrences of this variant, thinly laminated siltstone and ripple cross-laminated sandstone at the base are replaced by a thick accumulation of horizontally laminated sandstone. The sequence continues to coarsen upwards as gravel laminae and lenses become more abundant. Rare Palaeophycus occur within interbedded siltstone and sandstone strata (Cudzil and Driese, 1987).

The horizontally laminated sandstone of this variant is interpreted to have been deposited under upper plane-bed conditions. Parallel laminations and low-angle cross-laminations have been documented in Pleistocene outwash-plain deposits (Reugg, 1977), as well as in overbank deposits of modern ephemeral and perennial braided rivers (McKee, Crosby, and Berryhill, 1967; Boothroyd and Ashley, 1975). In the case of the ephemeral Bijou Creek (McKee and others, 1967), a single flash flood event deposited up to 3.5 m of horizontally laminated sand.

The other sedimentary features present indicate periodic fluctuations in Froude Number, that is, either changes in velocity or flow depth, or both. The complete stratification sequence records a single flood event. The basal conglomerate-filled scour indicates the beginning of the high-energy event, during which medium- to coarse-grained sediment was winnowed away leaving a gravel lag. Alternatively, sediment could have been deposited as bedload within a scour. The filled scour is overlain by low-angle to horizontally laminated sandstone, which commonly contains low-angle truncation surfaces. These surfaces probably result from the scour of a previous deposit prior to deposition during the later flood event. Small-scale cross-stratification rarely caps the entire sequence, indicating deposition under decreasing Froude Number. Although the above sequence is not the most common in this variant, its presence indicates that this variant was deposited by an amalgamation of flood events. Because structures indicating lower flow-regime would have the lowest preservation potential in this hypothetical depositional setting, thick accumulations of laminated sand could very well develop.

This variant is therefore interpreted as a group of vertical accretion deposits on an alluvial braidplain. The coarsening-upward nature of each occurrence may be a reflection of the proximity of an active braid channel. As the braid channel migrated the overbank deposits gradually became coarser. The interbedded siltstone and sandstone at the bottom of each occurrence of this variant probably resulted from deposition from suspension and under lower flow-regime conditions. The presence of *Palaeophycus* within these fine-grained lithologies is interpreted as representing the marine influence on the alluvial plain, probably in a saltwater pond that gradually filled with flood-plain deposits as the braid channels migrated. Alternatively, the coarser channel deposits may be interpreted as representing deposition in shallow marine tidal channels. Precise assignment of individual beds to shallow marine or distal braidplain environments based strictly on the presence or absence of trace fossils can easily lead to faulty interpretations. Marine and terrestrial processes co-exist on several coastal plains (e.g., Skeidarasandur of Iceland, Hine and Boothroyd, 1978; Yallahs fan delta of Jamaica, Wescott and Etheridge, 1980; southeast coast of Alaska, Boothroyd and Ashley, 1975; Copper River delta, Galloway, 1976). The proximity of a shoreline during the time of conglomerate facies deposition is also evidenced by the interbedding of the facies with both the sandstone facies and the lower quartz arenite facies.

In summary, the conglomerate facies is a result of deposition within subenvironments of a braided stream plain where active channels flowed into an adjacent marine system. The braid plain was a mosaic of channels with large transverse and longitudinal bars, channel pool areas with megarippled gravel and silt deposited during waning flood stage, amalgamated sheet-flood deposits and brackish flood-plain pond deposits (Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988).

Interlaminated Mudstone - Sandstone Facies

This facies is characterized by interlaminated mudstone and sandstone resulting in a distinctive "pinstripe" appearance. The sandstone component tends to increase in prominence upsection, culminating in the occurrence of very thin sandstone beds at the top of the interval. This increase in sandstone content is accompanied by a change in the geometry of the individual laminae. Near the base, individual laminae tend to be lenticular, but become laterally continuous upsection. Many of the sandstone laminae pinch-and-swell, and are internally cross-laminated and appear to represent a transition from the interlaminated mudstone-sandstone facies to the horizontally laminated variant of the conglomerate facies (Skelly, 1987).

The characteristic appearance of the interlaminated mudstone-sandstone facies closely resembles varves of lacustrine origin. The restriction of this facies to an interval bound by deposits of the conglomerate facies indicates non-marine sedimentation associated with braided stream deposition. Conversely, if the conglomerate lithologies represent shallow marine tidal channel deposition, as previously discussed, these fine-grained deposits may be interpreted as representing lagoon or tidal pond deposition. While in some respects, this facies is very similar to overbank floodplain deposits described from various fluvial systems, many features are inconsistent with such an interpretation. The distribution of sandstone within this interval suggests a general shallowing- and coarsening upward trend. This trend and the great thickness of this facies at its single occurrence (27 m) seems inconsistent with deposition as overbank in a braided stream system. Alternatively, this shallowing-upward trend suggests constant, yet gradual infilling of a small-body of standing water, possibly located within the more stabilized portions of the braidplain of the braided stream system represented by the conglomerate facies (Skelly, 1987).

Sandstone Facies

The sandstone facies is mineralogically and texturally more mature than the conglomerate facies, consisting predominantly of subarkosic to arkosic arenite, with subordinate amounts of siltstone. Quartz and feldspar are the primary components; rock fragments are absent. Grain size ranges from fine sand to granules. Grains are rounded to well-rounded and moderately sorted. Glauconite is a locally abundant constituent of the sandstone facies in the Erwin Formation (and its equivalents). However, no glauconite was observed in the underlying formations. The sandstone facies occurs throughout the entire Chilhowee Group exposure (Figs. 3-6, 3-7, 3-8, and 3-9).

Ranging in thickness from 0.1 to 1.5 m, beds of this facies are characterized by small- to large-scale, planar-tabular or trough cross-stratification. Variations in set thickness define thinning-upward sequences, which are 10 to 20 m thick. Grain size decrease is prevalent within the thinning-upward sequences. Large-scale sets or cosets of cross-strata are found in the lower parts of the thinning-upward sequences. Lower portions of these sequences commonly possess thick beds of inversely graded, conglomeratic sandstone. Individual set boundaries are marked by discontinuous

FIG. 3-6. - Measured section of the Chilhowee Group at Bean Mountain, Tennessee. Thicknesses are in meters. Facies are labelled as follow: G = **Conglomerate** facies; M = **Mudstone - Siltstone** facies; Q = **Quartz arenite** facies; and H = **Hummocky** facies.

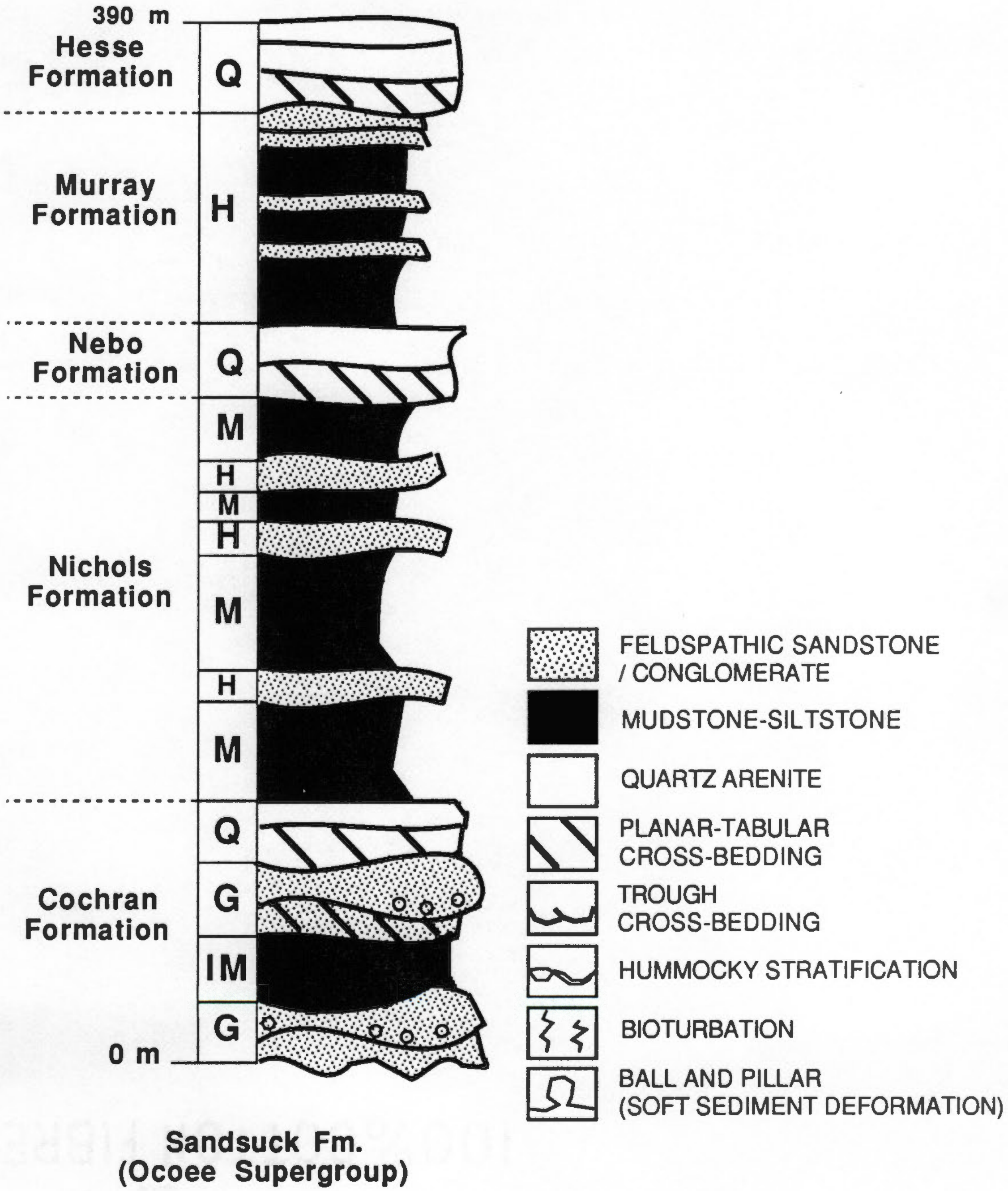

390 m
Hesse Formation
Q
Murray Formation
H
Nebo Formation
Q
M
H
M
H
Nichols Formation
M
H
M
Q
Cochran Formation
G
IM
G
0 m
Sandsuck Fm. (Ocoee Supergroup)
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE
PLANAR-TABULAR CROSS-BEDDING
TROUGH CROSS-BEDDING
HUMMOCKY STRATIFICATION
BIOTURBATION
BALL AND PILLAR (SOFT SEDIMENT DEFORMATION)

FIG. 3-7. - Measured section of the Chilhowee Group at Chilhowee Mountain, Tennessee. Thicknesses are in meters. Facies are labelled as follow: G = **Conglomerate** facies; M = **Mudstone - Siltstone** facies; S = **Sandstone** facies; Q = **Quartz arenite** facies; and H = **Hummocky** facies. See Figure 3-6 for key to sedimentary symbols.

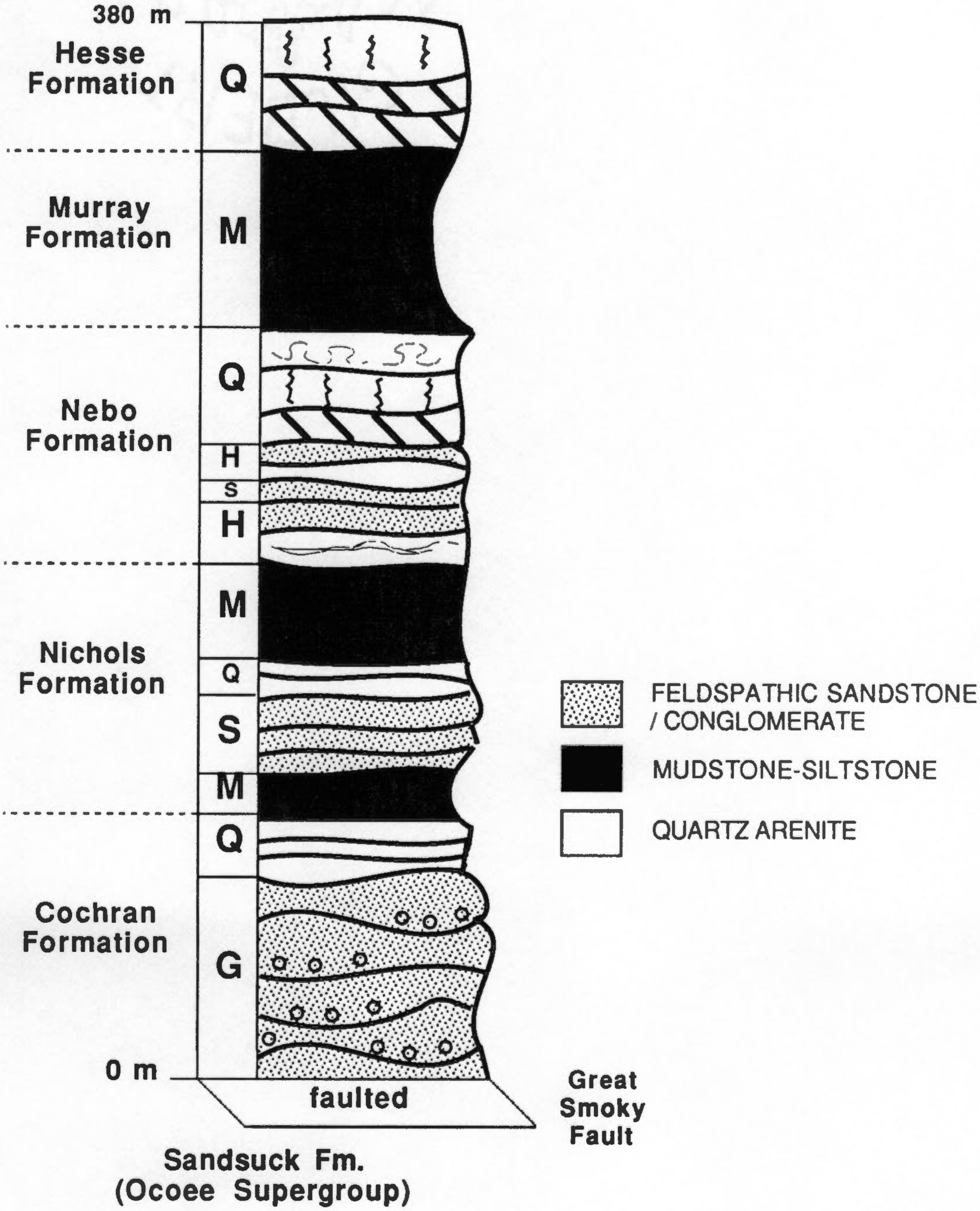
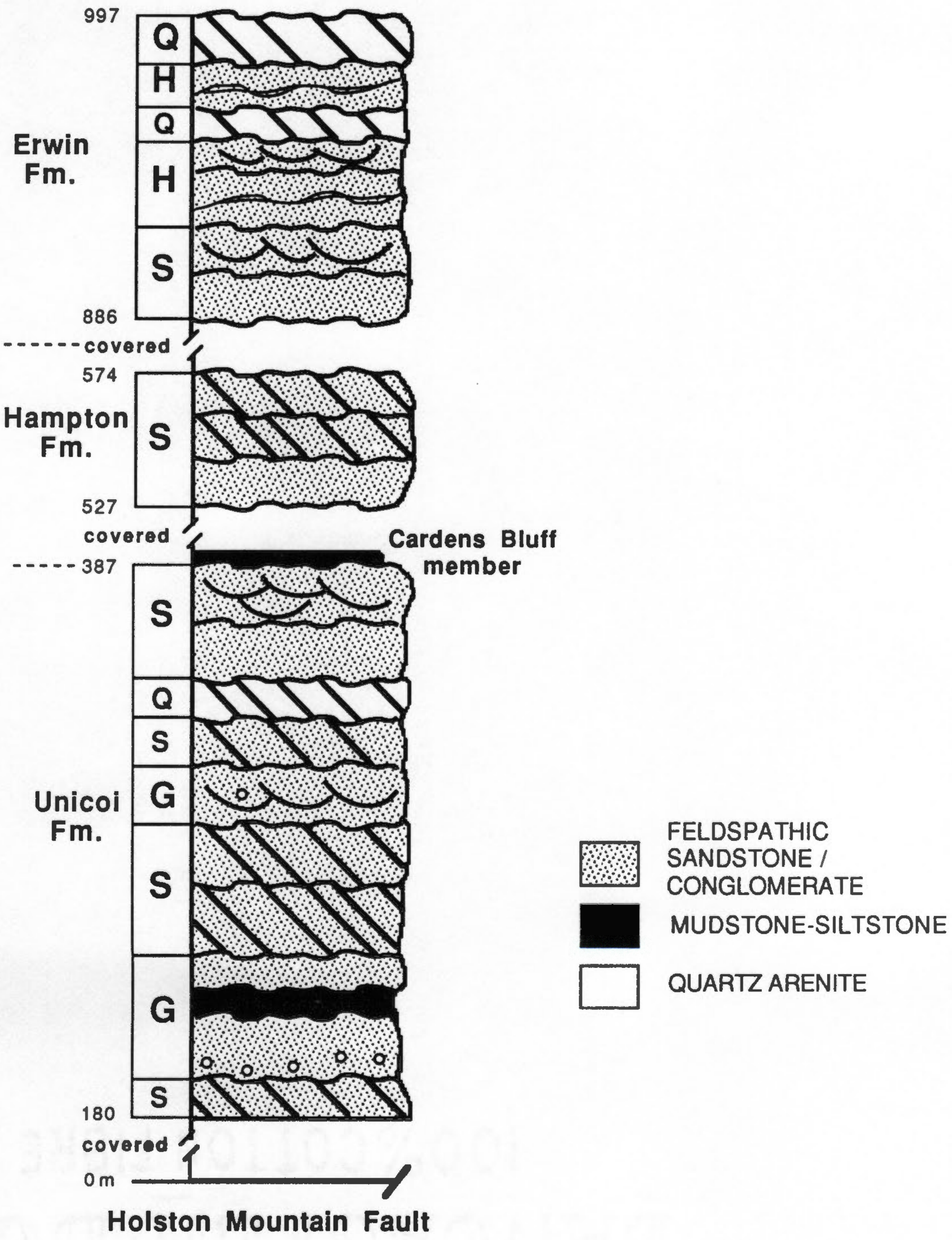
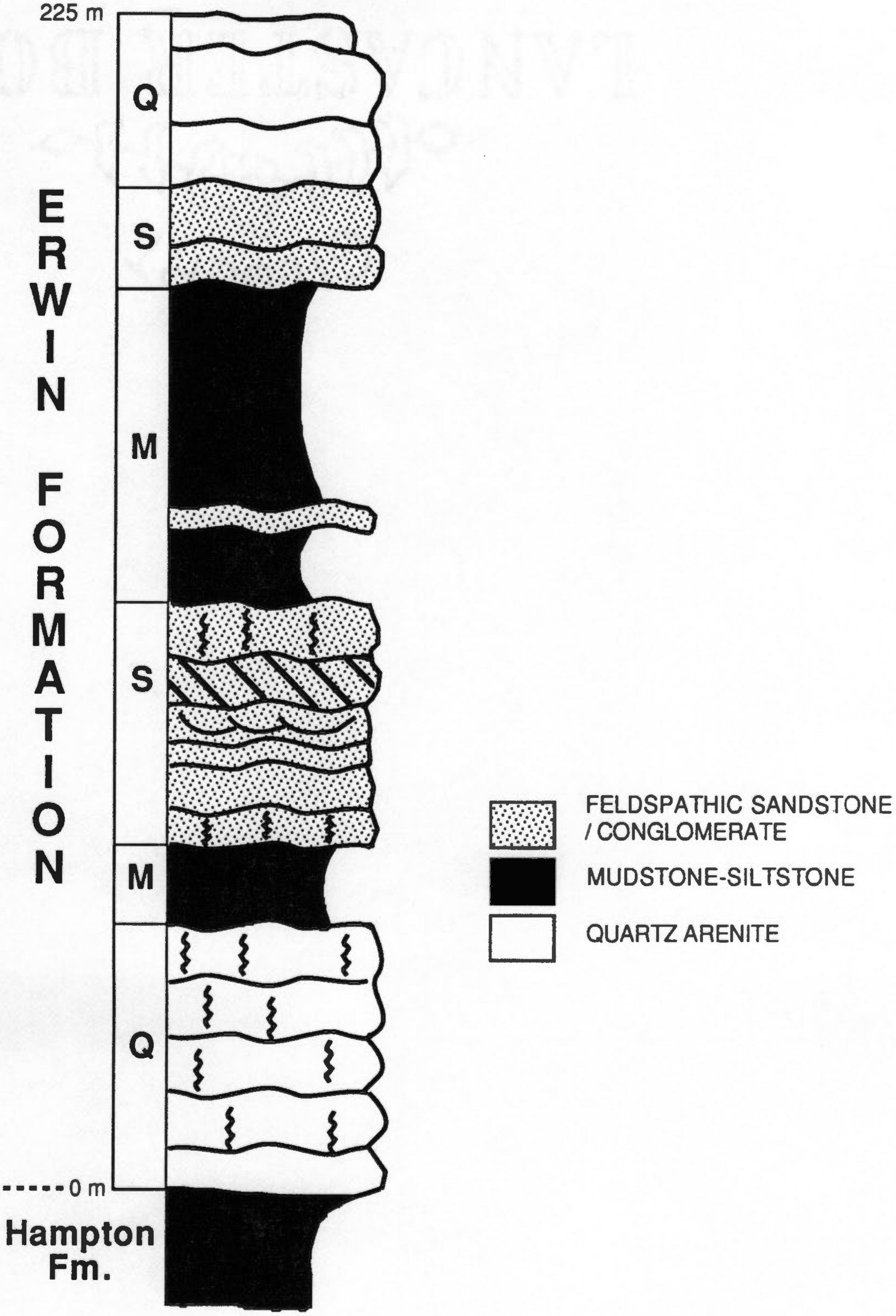

380 m
Hesse Formation
Q
Murray Formation
M
Nebo Formation
Q
H
S
H
Nichols Formation
M
Q
S
M
Cochran Formation
Q
G
0 m
faulted
Great Smoky Fault
Sandsuck Fm. (Ocoee Supergroup)
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE

FIG. 3-8. - Measured section of the Chilhowee Group at Valley Forge, Tennessee. Thicknesses are in meters. Facies are labelled as follow: G = **Conglomerate** facies; M = **Mudstone - Siltstone** facies; S = **Sandstone** facies; Q = **Quartz arenite** facies; and H = **Hummocky** facies. See Figure 3-6 for key to sedimentary symbols.



997
Q
H
Q
Erwin Fm.
H
S
886
covered
574
Hampton Fm.
S
527
covered
Cardens Bluff member
387
S
Q
S
Unicoi Fm.
G
S
G
S
180
covered
0 m
Holston Mountain Fault
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE

FIG. 3-9. - Measured section of the Chilhowee Group along Interstate 40 south of Newport, Tennessee. Thicknesses are in meters. Facies are labelled as follow: M = **Mudstone - Siltstone** facies; S = **Sandstone** facies; Q = **Quartz arenite** facies; and H = **Hummocky** facies. See Figure 3-6 for key to sedimentary symbols.


225 m
Q
S
M
S
M
Q
ERWIN FORMATION
0 m
Hampton Fm.
FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE

siltstone partings. Very-coarse grained sand or granule lags are common near the base or top of a set or coset. Foresets are commonly graded and range in thickness from 0.01 to 0.03 m, and are typically devoid of small-scale cross-stratification. Cosets or large-scale sets may be reduced in thickness by as much as 50 percent within each thinning-upward sequence, with the relief seen on outcrop reflecting either the topography of the original bedform or subsequent scour (Cudzil and Driese, 1987).

Upper portions of thinning-upward sequences typically display medium-scale, planar-tabular and trough cross-stratification. The fundamental repeated sequence is as follows: medium-scale cross-stratification possessing a flat to wavey base, overlain by small-scale cross-lamination, with a laminated siltstone / sandstone layer then draping the cross-stratified bed. Although small-scale cross-laminations are common, ripple marks are not abundant in the sandstone facies. However, when present they tend to be straight-crested, simple to bifurcating wave ripples with rounded to flattened crests. The fine-grained layers that overlie the cross-stratified sandstone commonly range in thickness from .01 to 1 m, and consist of intercalated laminated to thin-bedded, micaceous siltstone and fine- to coarse-grained sandstone. Although the interbeds of sandstone within the siltstone sequences commonly occur as single-grain-layers, some intervals display thin beds of sandstone which may be characterized by wavey to lenticular bedding, with unidirectional ripple cross-laminations.

Trace fossils of the sandstone facies are absent in the Unicoi-Cochran interval, with bioturbation gradually increasing upsection through the Hampton-Nichols Formation and into the Erwin-equivalent interval. Bioturbation within the sandstone facies of the Hampton-Nichols is of two types: 1) horizontal burrows disrupting fine-grained interbeds, and 2) rare occurrences of single or paired vertical burrows. Conversely, bioturbation of the sandstone facies within the Erwin is quite common, but again tends to be concentrated in the fine-grained layers, and may include *Palaeophycus*, *Rusophycus*, and *Cruziana*. This facies is devoid of vertical traces within the Erwin Formation. (Cudzil and Driese, 1987, see Chapter 2 for more discussion).

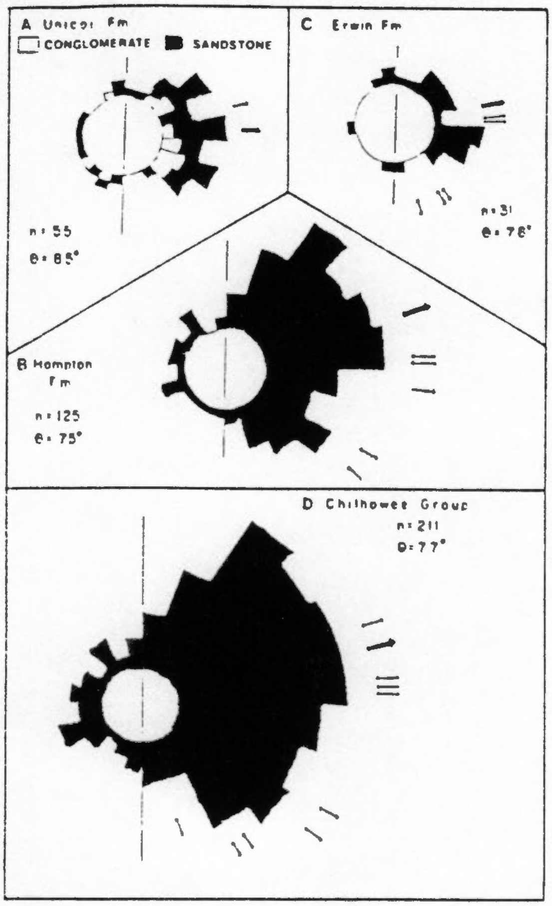
The sandstone facies is interpreted to represent marine shoreface deposition. The submature to mature nature of this facies probably reflects reworking of fluvial sediment by waves and/or tides. The subordinate amount of siltstone indicates that deposition must have occurred within a system experiencing random fluctuations in current strength. The large-scale cross-stratification of this facies is interpreted as representing deposition within broad subtidal channels dominated by storm-enhanced tidal and/or rip currents. While channel-shaped scours were not observed, the basal lag of the large-scale sets records the scour over which the large bedforms migrated. Medium- and small-scale features were formed in shallower water, possible representing the existence of shoals adjacent to the channels (Cudzil and Driese, 1987).

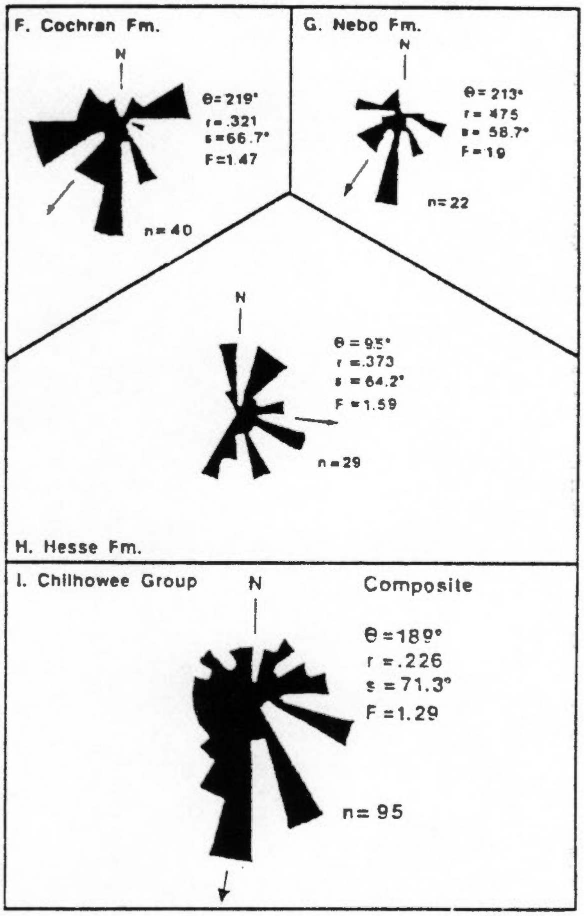
Except for the rare occurrence of herring-bone cross-stratification, evidence for unsteady bi-directional currents is absent (i.e., reactivation surfaces, clay drapes, tidal bundles or counter-flow ripples). Therefore, these small- to large-scale cross-sets probably formed in response to steady uni-directional current. Rapid and marked velocity reduction resulted in the fining-upward couplet of the cross-stratified sandstone and the overlying siltstone. This period of low to zero velocity may have occurred during slack-tide (Klein, 1977; McCave, 1970), or after the waning stages of tidally- or storm-enhanced current activity (Davidson-Arnott and Greenwood, 1976). During renewed current activity, the low energy silt and sand layers were wholly or partially eroded as megaripple migration resumed. (Cudzil and Driese, 1987).

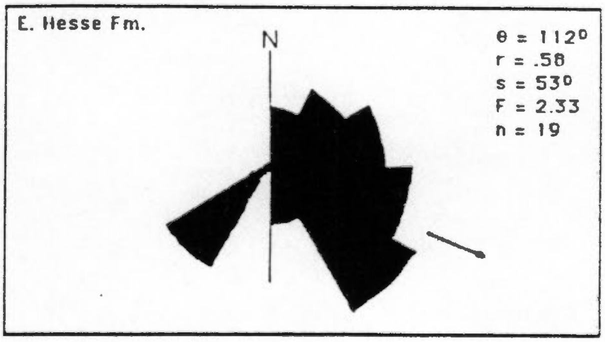
Whether sediment of the sandstone facies was deposited in response to tidal currents, longshore currents, or some combination of the two regimes is unclear. Reactivation surfaces and/or clay drapes, features diagnostic of reversing flow (de Mowbray and Visser, 1984) are absent. Likewise, features indicative of wave activity, such as wave ripples or hummocky stratification, are rare. The few occurrences of symmetrical ripples observed, are typically flattened, with internal lamination not visible.

Information in the form of paleocurrent data is likewise ambiguous, and are summarized in Fig. 3-10 (Cudzil and Driese, 1987, n = 211; Skelly, 1987, n = 95; Walker and others, 1988; n = 19). The data are unimodal, but dispersed between 0^o and 180^o, with a minor mode directed to the west (Fig. 3-10). Ancient shallow-marine sequences typically display a widely dispersed (polymodal) paleocurrent pattern, possibly resulting from the complex interaction of different current systems (Pettijohn, Potter, and Siever, 1973). Tide-dominated settings generally display bimodal patterns, with the largest mode representing the dominant tidal phase. However, tidal cycles are characteristically unequal in terms of the magnitude and duration of the ebb and flood phases (Klein, 1977). Furthermore, ebb and flood currents may follow mutually

FIG. 3-10. - Paleocurrent rosettes for Valley Forge (A-D), Chilhowee Mountain (E), and Bean Mountain (F-I) localities. Data are from Cudzil, 1985, n = 211; Cudzil and Driese, 1987; Skelly, 1987, n = 95; Walker and others, 1988, n = 19.


A Unicoi Fm
CONGLOMERATE
SANDSTONE
n = 55
θ = 85°
C Erwin Fm
n = 31
θ = 78°
B Hampton Fm
n = 125
θ = 75°
D Chilhowee Group
n = 211
θ = 77°


F. Cochran Fm.
N
θ= 219°
r = .321
s = 66.7°
F=1.47
n= 40
G. Nebo Fm.
N
θ = 213°
r = .475
s = 58.7°
F = 19
n= 22
N
θ = 95°
r = .373
s = 64.2°
F = 1.59
n = 29
H. Hesse Fm.
I. Chilhowee Group
N
Composite
θ = 189°
r = .226
s = 71.3°
F = 1.29
n= 95


E. Hesse Fm.
N
θ = 112°
r = .58
s = 53°
F = 2.33
n = 19

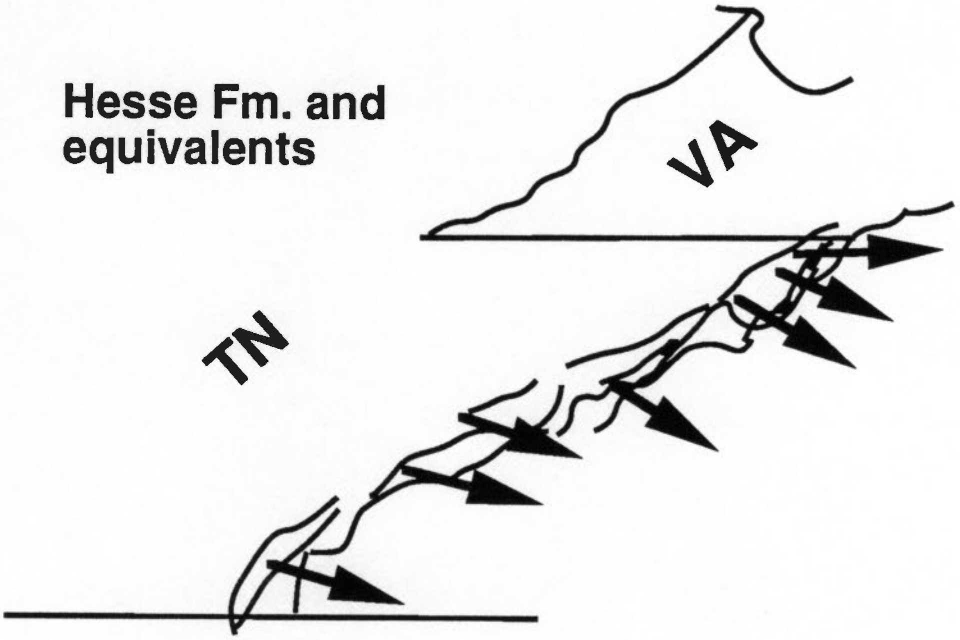
exclusive paths (Walker, 1984), resulting in a unimodal paleocurrent pattern (Cudzil and Driese, 1987).

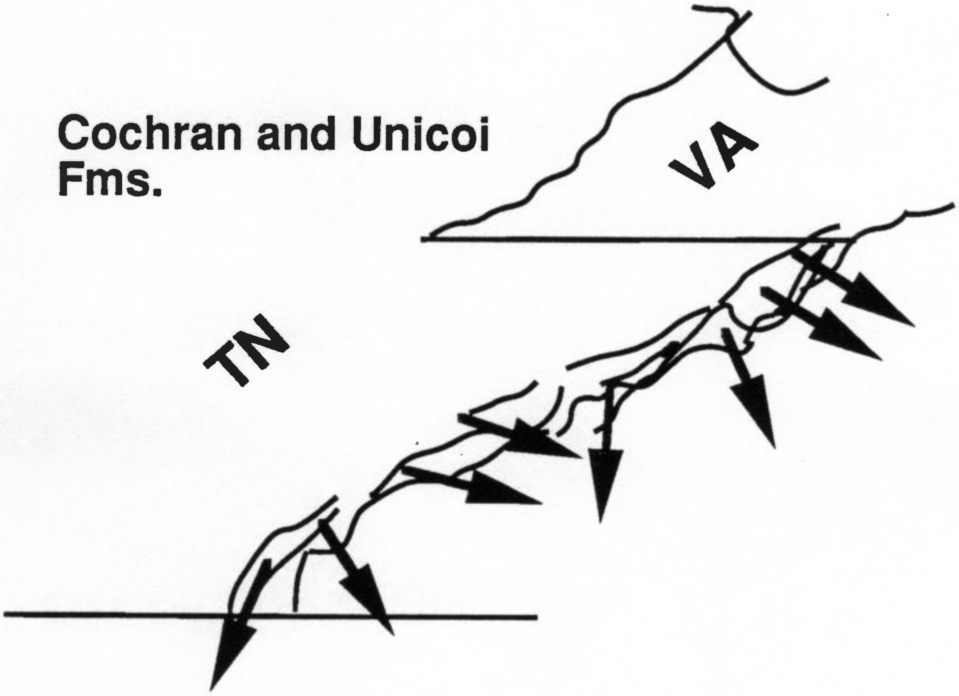
Ancient wave-dominated clastic shorelines typically display paleocurrent patterns, which are directed onshore, offshore and alongshore (Heward, 1981). In order to make inferences based on such data, the location of the paleoshoreline is required. The establishment of a position of paleoshoreline is difficult for the Chilhowee Group. Regional paleocurrent patterns for the Unicoi-Cochran interval (braided alluvial) are typically directed east and southeast (Fig. 3-11A) (Schwab, 1972; Whisonant, 1974; Skelly, 1987) and presumably reflect the paleoslope. These data then argue for a paleoshoreline, which may have generally trended N - S or NE - SW. If such an orientation is correct, currents were then directed offshore and alongshore, with a minor mode directed onshore (Fig. 3-10D). This pattern is then interpreted as reflecting a mixing of tidal and wave influences. The dominant eastward transport and lesser westward mode might then reflect the more strength or duration of the ebb-tidal phase, relative to the flood phase (Cudzil and Driese, 1987).

The sandstone facies is therefore interpreted as representing shallow-marine sedimentation. The occurrence of interbedded rocks of the sandstone facies with those of the conglomerate facies, within the lower portion of the Unicoi Formation (Fig. 3-8), indicates the existence of a proximal, periodically prograding coastline. The increased dominance of the sandstone facies in the upper part of the Unicoi Formation, may reflect tidal channel migration in response to sediment-laden longshore currents. This migration resulted in the deposition of thinning- and fining-upward channel-fill sequences. Because of the lack of beach or eolian features, or spit-platform deposits, this area probably never developed a tidal inlet or barrier island. Thus, the German Bay area (Reineck and Singh, 1980) with its well-developed tidal channels and shoals, probably serves as the best modern analogue available (Cudzil and Driese, 1987).

In summary, the sandstone facies represents deposition within subtidal channels or on adjacent shoals. Thus, deposition during Unicoi and Hampton time occurred above fairweather wave-base, as evidenced by the flattened, symmetrical ripples and the lack of diagnostic storm features. Equivalent strata within the overlying Erwin Formation then represent slower sedimentation on the megarippled shoals and channels which were

FIG. 3-11. - Regional paleocurrent trends through time. From Skelly, 1987 (compiled from Schwab, 1972; Whisonant; 1974).


Hesse Fm. and
equivalents
VA
TN


Cochran and Unicoi
Fms.
VA
TN

located in deeper water. This environmental shift is documented by: (1) the change from a *Skolithos*-type trace assemblage to the *Cruziana*-type assemblage; (2) the interbedding of the sandstone facies with hummocky facies storm sandstone beds; (3) the presence of glauconite within the Erwin Formation (Cudzil and Driese, 1987).

The thick sequences of the sandstone facies of the Unicoi Formation are the result of stacking of tidal-channel-fill sequences (Fig. 3-8). Sedimentation during Unicoi time must have been keeping pace with subsidence/transgression in the area to allow for the development of such thick accumulation without any evidence for progradation into deeper water (Cudzil and Driese, 1987).

Mudstone-Siltstone Facies

This facies is characterized by its fine-grained nature, and a fairly diverse suite of sedimentary structures. Because of its fine-grained nature, it is generally poorly exposed, and thus may actually constitute much of the extensive covered intervals, common within the Chilhowee Group throughout the area. Where exposure is optimal, it forms monotonous sequences which may contain thin (.005-01 m), hummocky stratified sandstone beds (Fig. 3-5B). The finer-grained intervals display planar lamination, low-angle and symmetrical ripple cross-lamination, and locally abundant glauconite (Skelly, 1987; Walker and others, 1988). Bioturbation is common and results in disrupted laminae and a mottled coloration. Both *Planolites* and *Palaeophycus* traces were observed (Skelly, 1987).

The fine-grained nature of this facies and the occurrence of wave produced sedimentary structures suggests deposition above normal wave base during fairweather conditions. The local abundance of glauconite suggests slow sedimentation rates, possibly associated with transgressive periods in which coarser sediment was trapped in recently formed estuaries. The occurrence of thin, hummocky stratified sandstone beds within the finer-grained intervals indicates periodic storm-activity resulting in the influx of coarser sediments (Skelly, 1987; Walker and others, 1988).

Hummocky Facies

The hummocky facies consists of laminated, fine-grained micaeous arkosic arenite and bioturbated siltstone, with locally abundant glauconite. The individual siltstone and sandstone beds range in thickness from 0.01 m to 0.20 m, although some sandstone beds may range up to 0.7 m in thickness. The typical complete stratification sequence (Fig. 3-5E) consists of the following (bottom to top): (1) flat, sharp-based planar-laminated sandstone, possessing tool or drag marks, parting lineation, and wrinkle marks on the bed soles; (2) hummocky cross-stratification; (3) a second zone of planar lamination; (4) a layer of symmetrical ripple forms with unidirectional cross-lamination; (5) bioturbated siltstone +/- thin sandstone lenses. Similar complete sequences have been reported by Dott and Bourgeois (1982).

The complete sequence described above is rarely recorded in the rock record, and variations of the ideal sequence are much more numerous (Fig. 3-5D). Two end-member variants are commonly observed. In one variant, equal amounts of siltstone and sandstone are very thinly to thinly interbedded. Sandstone beds general have wavy bases and tops and are so heavily bioturbated that internal stratification is lost. In those intervals where bioturbation is more restricted, these beds may exhibit ripple cross-lamination. Within the thicker (0.1 to 0.3 m) sandstone beds, most of the ideal sequence is preserved. However, the other end-member variant consists of 0.7 m thick beds of horizontally and evenly laminated sandstone; siltstone and hummocky zones are absent (Cudzil and Driese, 1987).

The ideal sequence and its end-member variants are commonly arranged in a 1 to 8 m thick coarsening-upward package (Fig. 3-5D). At the base of such a sequence the siltstone and sandstone are roughly equally interbedded. As siltstone content decreases, the thickness of the sandstone beds increases, and the occurrences of complete sequences become more numerous. Furthermore, sharp-based and flat-topped sandstone beds composed solely of planar-laminated sand become more common, until finally a 0.5 to 0.7 m planar-laminated sandstone bed caps the entire sequence. The sequence is then repeated, so that equally interbedded siltstone and sandstone directly overly the planar-laminated sandstone cap (Cudzil and Driese, 1987).

Two types of soft-sedimentary deformation features are commonly observed within the hummocky facies. These include convolute laminae and ball-and-pillow structures. Deformed laminae are apparently restricted to beds less than 0.2 m thick. Conversely, ball-and-pillow structures, consisting of laminated or unlaminated fine-grained sandstone, range from 0.3 to 1.5 m in diameter. Several examples of truncated ball-and-pillow structures were observed, indicating erosion prior to the deposition of the overlying siltstone and sandstone (Cudzil and Driese, 1987).

The trace fossil assemblage characteristic of the hummocky facies is composed of *Rusophycus*, *Cruziana*, and horizontal and subhorizontal burrows. The assemblage is thus identical to that found within the fine-grained layers of the sandstone facies of the Erwin Formation (Cudzil and Driese, 1987).

The occurrence of interbedded sandstone / siltstone and hummocky cross-stratification, the two most significant environmental indicators, indicates deposition in a storm-dominated shelf or lower shoreface environment (Walker, 1984; Dott and Bourgeois, 1982). Sedimentation probably occurred between fairweather and storm wave-base. The occurrence of glauconite within the hummocky facies indicates proximity to a quiet-water environment dominated by slow sedimentation (Odin and Matter, 1981; Cudzil and Driese, 1987).

Although the process responsible for the formation of complete hummocky sequences has generated some debate (Harms and others, 1982; Dott and Bourgeois, 1982; Swift and others, 1983; Walker, 1984), most workers conclude that storm waves provide the energy required to scour the seafloor and transport or resuspend sediment. Swift and others (1983) documented the production of hummocky sea-floor by a combined flow regime. Hummocky megaripples were produced by the interaction of a mean flow component transporting sediment along shore with a second, wave-orbital component. Swift and others (1983) then synthesized their observations on the Atlantic shelf to produce a process-response model, similar to ones formulated by Dott and Bourgeois (1982) and Walker (1984) based on observations of hummocky stratification within the rock record (Cudzil and Driese, 1987).

The occurrence of soft-sediment deformation features suggest local, rapid sedimentation. Modern shelf sediment becomes quick and unstable in response to pressure pulses associated with storm waves (Nelson, 1982; Saxov and Nieuwenhuis, 1982). The occurrence of eroded ball-and-pillow structures documents the intense scouring present on the shelf (Cudzil and Driese, 1987).

Interpretation of the incomplete sequences. The significance of the end-member variants lies in the interpretation of the 1 to 8 m thick coarsening-upward sequences. They may reflect variation in several factors through time:

(1) fluctuations in relative sand supply;

(2) relative water depth;

(3) increased frequency, duration, and magnitude of storms; and

(4) proximity of strong tidal currents (i.e., magnitude of tidal range). The two end-member variants are similar to the micro-hummocky lenses type sequence and the amalgamated type sequence described by Dott and Bourgeois (1982; Cudzil and Driese, 1987).

The end-member variant characterized by thin beds and lenses of sandstone within bioturbated siltstone represents deposition from pulses of currents resulting from distal storm activity. Form-discordant wave-ripple lamination and micro-hummocky stratification were produced by combined unidirectional current deposition of sand and oscillatory flow modification of the storm layers. Thus, deposits of this end-member variant are interpreted to represent deposition in a deeper-water, more distal setting than that of the other sequences. These sand layers, therefore, represent the most distal reaches of the storm-dominated shelf (Cudzil and Driese, 1987).

The planar-laminated, fine-grained sandstone end-member variant represents erosion and deposition in areas located proximally to storm-generated currents. Thus, the 0.5 to 0.7 m thick beds represent an amalgamation of storm events. Complete sequences, generated by storm and wave currents, were partially eroded by subsequent events resulting in the selective preservation of the basal planar-laminated zone (Cudzil and Driese, 1987).

The coarsening-upward sequence reflects the interaction between the proximity and migration of a sand source, and more importantly, the proximity, magnitude, duration, and frequency of storms (Aigner and Reineck, 1982). Source area migration may be achieved by either shoreline progradation or by the migration of a local sand source in response to storm-surge ebb currents or tidal currents. On sand-starved shelves, sand patches may serve as a local sand source (Levell, 1980). The locally abundant glauconite within the Erwin Formation indicates deposition during restricted sediment input, and therefore the sand was probably locally derived. The sand source may also have migrated with shifting storm-surge ebb and tidal current pathways (Cudzil and Driese, 1987).

Conversely, sand may have been eroded from the shoreface and transported offshore. More definitive conclusions regarding the possible sand source cannot be made without more substantial knowledge of the position of the paleoshoreline. If the sediment was locally derived, storm sands were probably deposited down current from ridges and/or adjacent shoals (Cudzil and Driese, 1987). This gross sediment distribution pattern would then resemble that observed in the North Sea (Johnson, 1978) and in Bristol Bay of the southern Bering Sea (Sharma and others, 1972).

Lower Quartz Arenite Facies

The lower quartz arenite facies consists of 95-98 percent well-rounded, well-sorted mono-crystalline quartz. The remaining constituents include feldspar and minor zircon, tourmaline, and micro-crystalline quartz. Grain size ranges from medium- to very coarse- grained. The deposits of this facies commonly display low-angle and large-scale, planar-tabular cross-stratification. It is associated with both the sandstone and conglomerate facies in the Unicoi and Cochran Formations (Figs. 3-6, 3-7, and 3-8). The lower quart arenite facies locally possesses several low-relief erosional surfaces which serve to divide it into 1 m thick beds. These scour surfaces are typically marked by thin, discontinuous layers of red, ferruginous siltstone with thin laminae of heavy minerals and scattered granules. The siltstone commonly drapes the underlying rippled surface, which is formed by symmetrical interference ripple marks. The red color is attributed to iron-staining by hematite that occurs within the diagenetic clays which fill the pores and replace the feldspars grains. Commonly occurring above the scour surface are thin, discontinuous granule lenses (Cudzil and Driese, 1987).

The maturity of the lower quartz arenite facies suggests a marine origin; however, it is commonly interbedded with the fluvial conglomerate facies. This relationship suggests deposition in a foreshore or nearshore zone of a wave-dominated coastline that was closely associated with a braided alluvial system. This interpretation is substantiated by the occurrence of low-angle cross-stratification, defined by heavy mineral and graded laminae. This cross-stratification is indicative of wave swash and backwash in the foreshore zone (Clifton, 1969; Reineck and Singh, 1980; Reinson, 1984). The broad, shallow scours and gravel lags record initial beachface erosion. Large-scale, planar-tabular cross-stratification with azimuths oriented from 50^{o} to 211^{o} (Fig. 3-10) would then represent landward or obliquely landward migration of storm ridges or longshore bars (Davis and others, 1972). The thin, discontinuous lenses of laminated silty conglomerate that drape the interference ripple marks is all that remains of the runnel or longshore trough deposit (Cudzil and Driese, 1987).

The widely dispersed paleocurrent pattern is probably the product of a complex current system. This system is the result of the interaction of waves, longshore currents, and tides coupled with the local influence of the nearshore topography (Cudzil and Driese, 1987).

The absence of finer-grained units, as well as its mature nature, strongly suggest that the lower quartz arenite facies reflects deposition in a high-energy nearshore environment. The interplay of storm and fairweather deposition resulted in highly reworked, mature sand. Sediment is continually transferred from the beach to the nearshore (storms) and then returned landward (fairweather), (Davidson-Arnott and Greenwood, 1976) resulting in a greater degree of sorting and rounding of the detrital grains.

The occurrence of sediment of this facies in association with that of the conglomerate facies further supports the interpretation of a nearshore marine origin (Fig. 3-6, 3-7, and 3-8). There are two modern examples of of the reworking of distal braided stream sediment by nearshore processes: (1) the Skeidarasandur shoreline (a glacial outwash plain shoreline) of the southern coast of Iceland (Hine and Boothroyd, 1978): and (2) the Yallahs fan delta of Jamaica (Wescott and Ethridge, 1980). In both localities waves impinge directly on fluvial deposits, producing features which reflect the dominance of waves and longshore processes and the relative minor role played by tides (Cudzil and Driese, 1987).

Upper Quartz Arenite Facies

Characterized by large-scale, planar-tabular cross-stratification, the upper quartz arenite facies is associated with both the hummocky and sandstone facies within the Erwin Formation (Fig. 3-5C). The base of each sequence is marked by a sharp, erosional surface, which truncates the underlying strata at low angles. These scour surfaces may extend for 10 to 15 m laterally, but typically show less than 0.5 m of relief. Although the beds appear internally massive, when viewed from a distance, planar-tabular cross-stratification with 0.3 to 0.5 m thick foresets becomes visible. Three occurrences of this facies were observed, each possessing a smooth upper surface devoid of any small-scale bedforms. The quartz arenite facies occurs in beds 1 to 9 m thick, each possessing a very coarse-grained basal lag. Each sequence is then overlain by 0.03 to 0.20 m of non-fissile shale with lenses of glauconite and very coarse quartz sand, and laminae of fine sand (Cudzil and Driese, 1987).

The mature nature of the upper quartz arenite facies, as well as its close association with both the hummocky and sandstone facies, strongly indicates it is marine in origin. Interpretation of the observed sedimentary structures and facies associations indicates that the strata of this facies were formed by detachment from shoreface ridges. The massive nature of the sandstone results in heavy emphasis being placed on the nature of the vertical sequence (Cudzil and Driese, 1987).

Large subtidal sand bodies, termed sand waves by Allen (1980), are defined as flow-transverse bedforms associated with reversing tidal currents. Sand waves possess a complex internal make-up, and may contain features commonly regarded as being diagnostic of tidal processes (e.g., clay drapes, reactivation surfaces) which may be arranged as tidal bundles (Visser, 1980; Allen, 1981; Allen and Homewood, 1984). The upper quartz arenite facies possesses none of these tidal features, which suggests that some other process must be responsible for the formation of these thick sandstone accumulations (Cudzil and Driese, 1987).

Shelf sand ridges, as discussed by Swift and Field (1981), originate as shoreface-attached ridges (i.e., as wave-built bars, produced by beachface erosion in the nearshore zone). On the shoreface, the ridges are affected by both storm-generated unidirectional flow as well as wave-orbital motion. During transgression, the affects of wave-orbital motion are decreased with increasing water depth. This change in the relative importance of unidirectional flow versus wave-orbital motion produces megaripples between the ridges. Thus, even the most seaward sand ridges are not true relict sediments, as they are continuing to respond to changing flows. The upper quartz arenite facies is interpreted as representing deposition on a storm-maintained shelf similar to the modern Atlantic shelf (Cudzil and Driese, 1987).

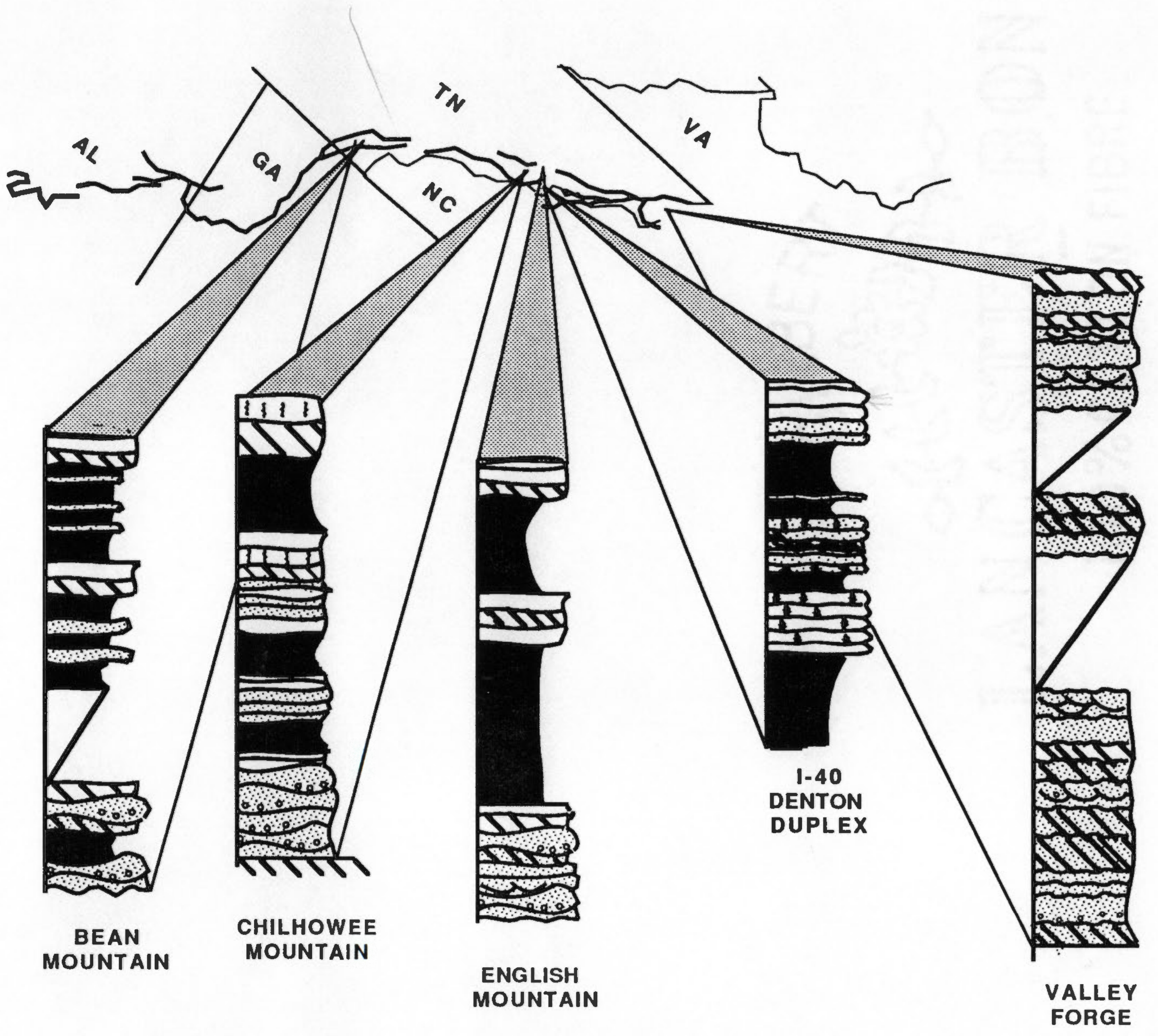
The thin granule/pebble lag which occurs along the upper surface of the the quartz arenite facies records winnowing by strong currents. Each sand body is then directly overlain by 0.3 m thick intervals of shale, which contain conglomerate lenses. This relationship may indicate rapid transgression, during which the shelf was only occasionally affected by large, long-period waves which served to segregate the coarse-grained sediments into lenses within the shale. Such waves have been documented as resulting in rippled sediment at depths of 200 m (Komar, and others, 1972). Rapid transgression results in the trapping of fluvial sediment in newly formed estuaries, thus sedimentation on the shelf is dominantly from suspension. The occurrence of glauconite within the conglomeratic lenses, while of little value for environmental analysis, indicates slow sedimentation rates (Cudzil and Driese, 1987). Transgressions, while restricting the influx of sediment from fluvial sources, also provide favorable conditions for glauconite formation because coarse sediment is submerged to greater depths where the effects of agitation are diminished (Odin and Matter, 1981).

In summary, the upper quartz arenite facies is interpreted as representing deposition within sub-tidal sand ridges on a storm-dominated shelf. The influence of tidal currents was apparently of secondary importance. The sandstone bodies are then hypothesized to be similar in origin to shoreface ridges of the storm-dominated Atlantic Shelf (Swift and Field, 1981). The lack of tidal influences, which constitutes negative evidence, forms the basis for this interpretation. As argued by Johnson (1978), similarities between tide- and storm-dominated sand ridges would make conclusions about the origin of such sand bodies, in the rock record, tentative at best (Cudzil and Driese, 1987).

Variations in Facies Distribution

The distribution of Chilhowee Group facies is not uniform across East Tennessee (Fig. 3-12). This variation results from two independent factors, which include: 1) variation in the distance from paleoshoreline during deposition (proximality); and 2) variation in the amount of tectonic transport experienced by each of the various Chilhowee exposures. Structural data previously described from Robert (1987) indicates that Chilhowee Group strata which display the 3-fold stratigraphy probably represent sedimentation in settings more proximal to the craton than Chilhowee Group strata displaying the 6-fold stratigraphy (Fig. 3-2 and 3-3). This relationship then suggests that during the latest Proterozoic and Early Cambrian, the Bean Mountain, Chilhowee

FIG. 3-12. - Distribution of Chilhowee Group facies at localities discussed in text.


AL
GA
TN
NC
VA
BEAN MOUNTAIN
CHILHOWEE MOUNTAIN
ENGLISH MOUNTAIN
I-40 DENTON DUPLEX
VALLEY FORGE

Mountain, and English Mountain localities occupied more distal settings, while the Valley Forge and I-40 localities occupied more proximal settings. The relationship of the localities within these two broad groups may the be elucidated based on the types and relative abundance of facies (and their variants) exposed at each locality.

TOTAL CONTRADICTION TO p. 51

As previously discussed, the proximal portion of modern braided stream systems is dominated by transverse bars, while the more distal portion can be characterized as possessing a higher proportion of longitudinal bars (Smith, 1970). The absence of the large-scale cross-stratified conglomerate variant (longitudinal bar deposits) from exposures at Chilhowee Mountain (Walker and others, 1988), as well as the restriction of the mudstone-sandstone facies (lacustrine-braid plain pool deposits) to exposures at the Bean Mountain locality, suggests that during Cochran deposition Bean Mountain occupied a more distal position with respect to the craton. This spatial relationship continued during marine deposition (Nichols through Hesse Formations) as documented by: 1) the absence of near shore deposits within the Nichols Formation at Bean Mountain, which are present in coeval strata at Chilhowee Mountain (Figs. 3-6 and 3-7); and 2) nearshore deposits of the Nebo Formation are thinner at Bean Mountain than those exposed at Chilhowee Mountain (Figs. 3-6 and 3-7; Skelly, 1987; Walker and others, 1988). Viewed collectively, this distribution of fluvial and marine facies indicates that the Chilhowee Mountain locality occupied a more proximal position (with respect to the craton) than that occupied by the Bean Mountain locality throughout Chilhowee Group deposition.

The Cochran-Unicoi interval at the I-40 locality was not adequately exposed to allow detailed facies analysis, hence comparison with coeval strata at the Valley Forge locality is not possible. Comparison of the Erwin Formation as exposed at both localities, results in the recognition that a greater portion of the strata exposed at the I-40 locality is comprised of nearshore deposits of the upper quartz arenite facies (Figs. 3-8 and 3-9). This single line of evidence suggests that the I-40 locality may have occupied a more proximal position (with respect to the paleoshoreline) than that occupied by the Valley Forge locality.

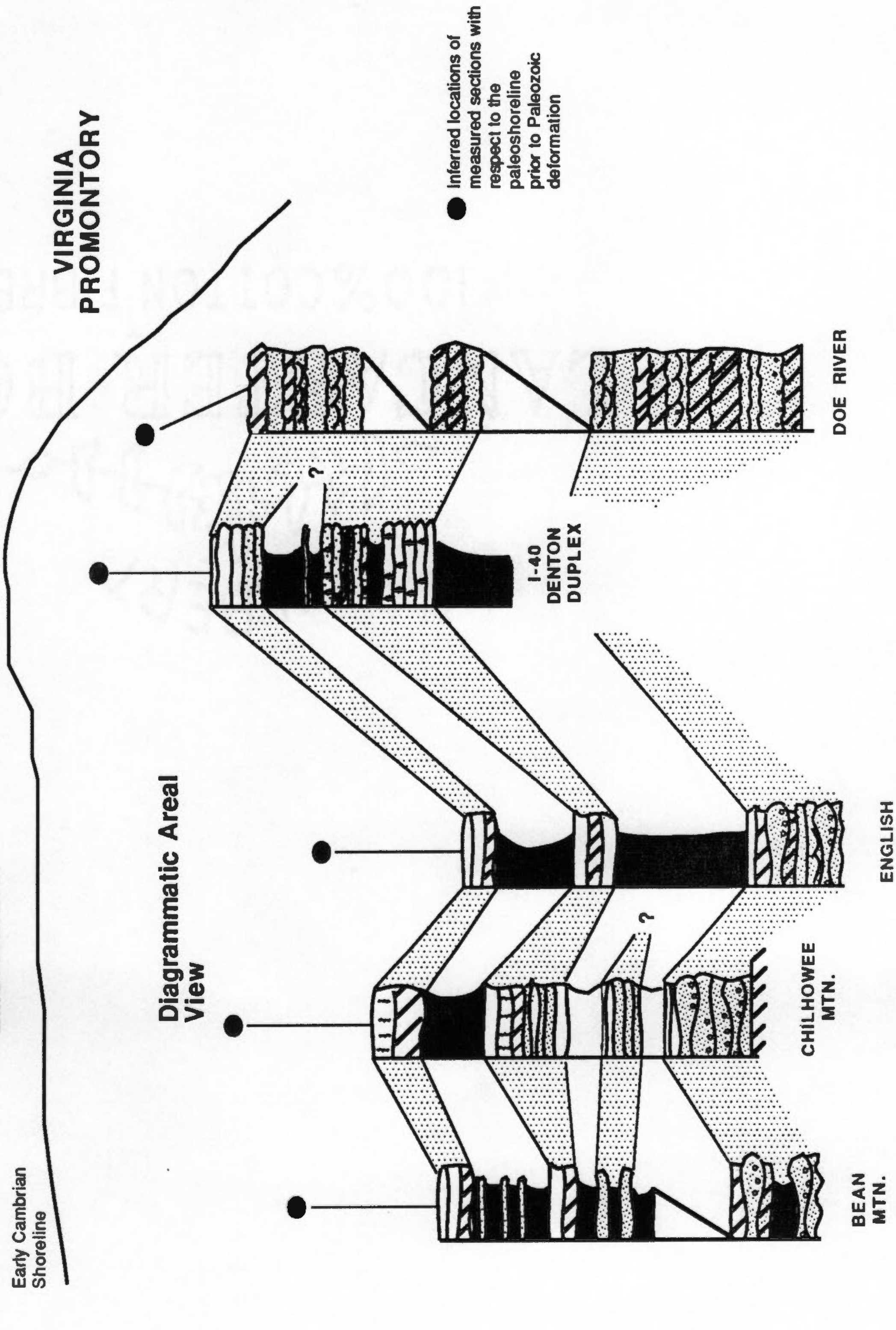
Examination of the available structural data (Fig. 3-3) as well as the distribution of facies described above suggest that the various localities can be arranged in terms of decreasing proximality (with respect to the craton) as follows: I-40 (most proximal), Valley Forge, Chilhowee Mountain, and Bean Mountain (most distal; Fig. 3-13). The occurrence of these localities (with demonstrable differences in proximality) along the essentially linear trend of the frontal Blue Ridge indicates that present day structural strike does not coincide with the latest Proterozoic to Early Cambrian depositional strike. Furthermore, the overall trend from more proximal deposition to more distal deposition can be characterized as both a northwest to southeast gradient, *and* a northeast to southwest gradient (palinspastic; Fig. 3-13). This geometry is consistent with previous suggestions (Rankin, 1975, 1976; Thomas, 1977, 1983) that the southern strike belts (Bean Mountain and Chilhowee Mountain) occupied a position within an embayment, while the northeastern strike belts (I-40 and Valley Forge localities) occupied a position adjacent to or within a promontory (Tennessee embayment and Virginia promontory, respectively; Thomas, 1983).

DEPOSITIONAL MODEL

Overall the Chilhowee Group comprises a large-scale, transgressive sequence associated with the stabilization of the southern Appalachian portion of the Iapetos continental margin. This transgression is most evident in the upward textural and compositional maturing displayed by all three sections discussed (Cudzil and Driese, 1987). Lower Chilhowee strata is interpreted as being fluvial in nature, while evidence of marine depositional processes increases upsection. This increase in marine influence indicates an increase in relative water depth due. This relative sea-level rise may be attributed to: 1) margin subsidence (associated with thermally induced density increase; Bond and others, 1984); 2) eustatic sea-level rise (possibly associated with multiple spreading center development (Ziegler and others, 1979)); 3) or some combination of the 1 and 2.

The relative positions of the various facies, with respect to paleo-shoreline, allows the construction of an idealized transgressive sequence based on the observed facies of the Chilhowee Group (Fig. 3-14, Table 3-1). Such a sequence of facies would tend to display an overall decrease in grain-size and bed thickness upsection. The observation of this sequence in the rock record would therefore suggest the stable interplay of constant rates of sedimentation and sea-level rise. Deviations from the ideal would then represent changes in the relative rates of these two extrinsic variables. Increase in sedimentation

FIG. 3-13. - Inferred palinspastic locations of Chilhowee Group sections discussed in text. Restored locations based on proximality of facies and structural data.



TENNESSEE EMBAYMENT
VIRGINIA PROMONTORY
Early Cambrian Shoreline
Diagrammatic Areal View
Inferred locations of measured sections with respect to the paleoshoreline prior to Paleozoic deformation
BEAN MTN.
CHILHOWEE MTN.
ENGLISH MTN.
I-40 DENTON DUPLEX
DOE RIVER
?
?

rate relative to sea-level rise would result in the production of regressive or progradational sequences. An ideal progradational sequence would then result in the inversion of the facies sequence proposed for the ideal transgressive sequence (Fig. 3-14).

The delineation of similar progradational sequences within the Chilhowee Group at Chilhowee Mountain permits the identification of three distinct phases of deposition, which are designated: 1) the initial basal fluvial-braided stream depositional phase, 2) progradational phase 1, and 3) progradational phase 2 (Fig. 3-15). These three phases were separated by rapid transgressive events, which juxtaposed deeper-water, outer-shelf environments over more proximal inner-shelf and shoreface environments.

Depositional Phase 1 is characterized by the occurrence of the massive variant of the conglomerate facies and comprises the entire Cochran Formation. Near the top of this interval, some interbedding with deposits of the lower quartz arenite facies occurs, suggesting gradual deepening and increased influence of marine processes. Thus this interval contains the fluvial-to-marine transition. Its upper boundary is marked by a sharp juxtaposition of outer shelf facies (mudstone-siltstone facies) over more proximal, inner shelf to shoreface facies (Lower quartz arenite facies). This transition is accompanied by a rapid decrease in both grain-size and bed thickness (Fig. 3-15).

Depositional Phase 2 is characterized by an overall progradational sequence composed of mudstone - siltstone facies through sandstone facies. Stratigraphically, it encompasses both the Nichols and Nebo Formations. Its upper boundary is marked by the sharp juxtaposition of the mudstone-siltstone facies over the upper quartz arenite facies. Unlike Phase 1, Phase 2 is entirely marine and contains a spectrum of marine facies. These facies are arranged into two smaller-scale sequences. The lower of these two sequences occurs in the lower portion of the Nichols Formation. and documents a smaller scale progradational event resulting in a correspondingly small coarsening- and thickening-upward sequence, which culminated in the upper quartz arenite facies. This interval contains the only known occurrences of *Skolithos* within the Nichols Formation. The upper of the two intervals cross the formational boundary and thus contains the upper portions of the Nichols and entire Nebo Formation. This upper sequence culminates with a thick interval of interbedded deposits of the sandstone and upper quartz arenite facies. Thick horizons of *Skolithos* occur, as well as a prominent horizon of soft sediment deformation, indicating that rapid sedimentation took place

FIG. 3-14. - Ideal transgressive sequence, based on observed facies of the fluvial-to-marine transition observed within the Chilhowee Group of East Tennessee.

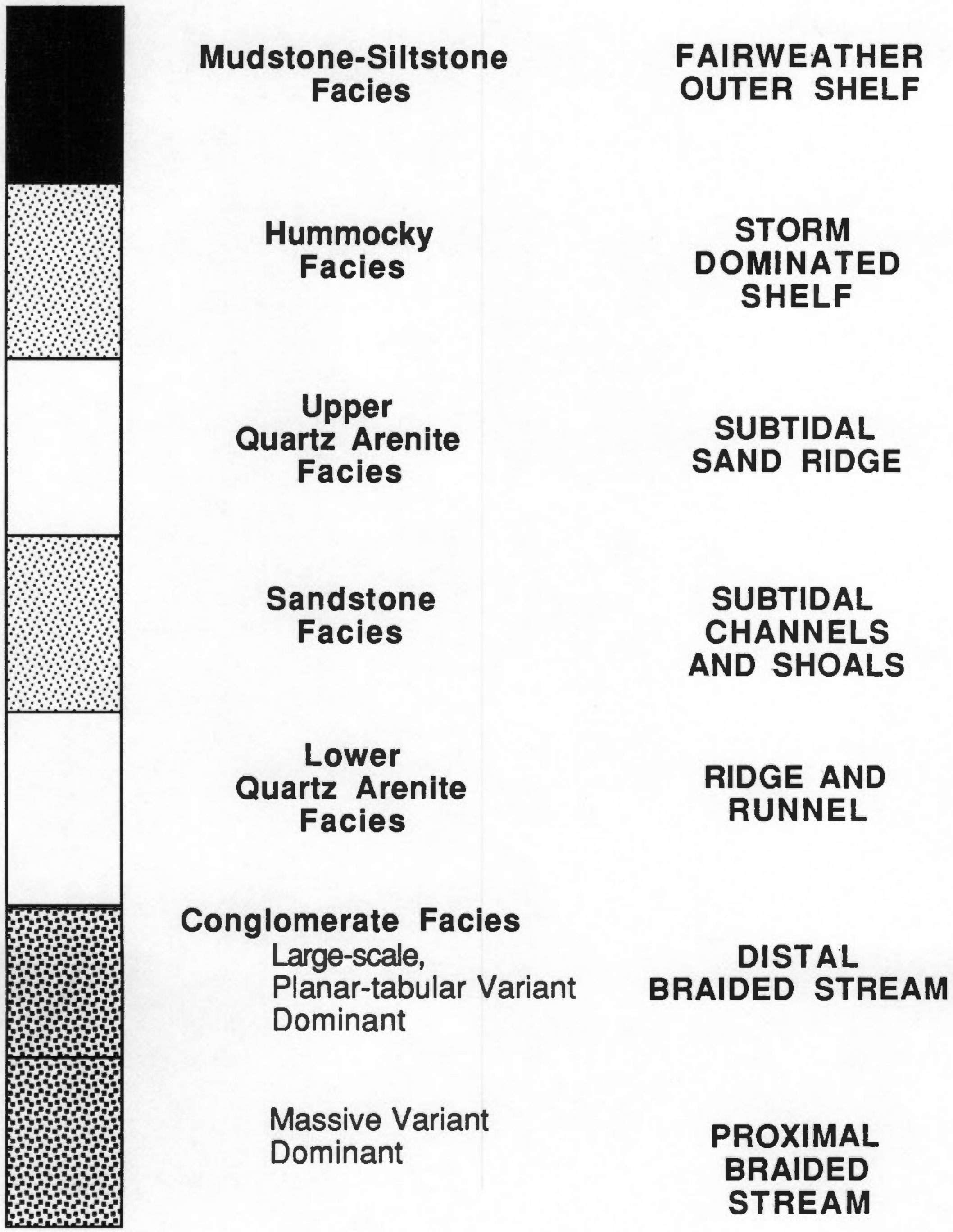
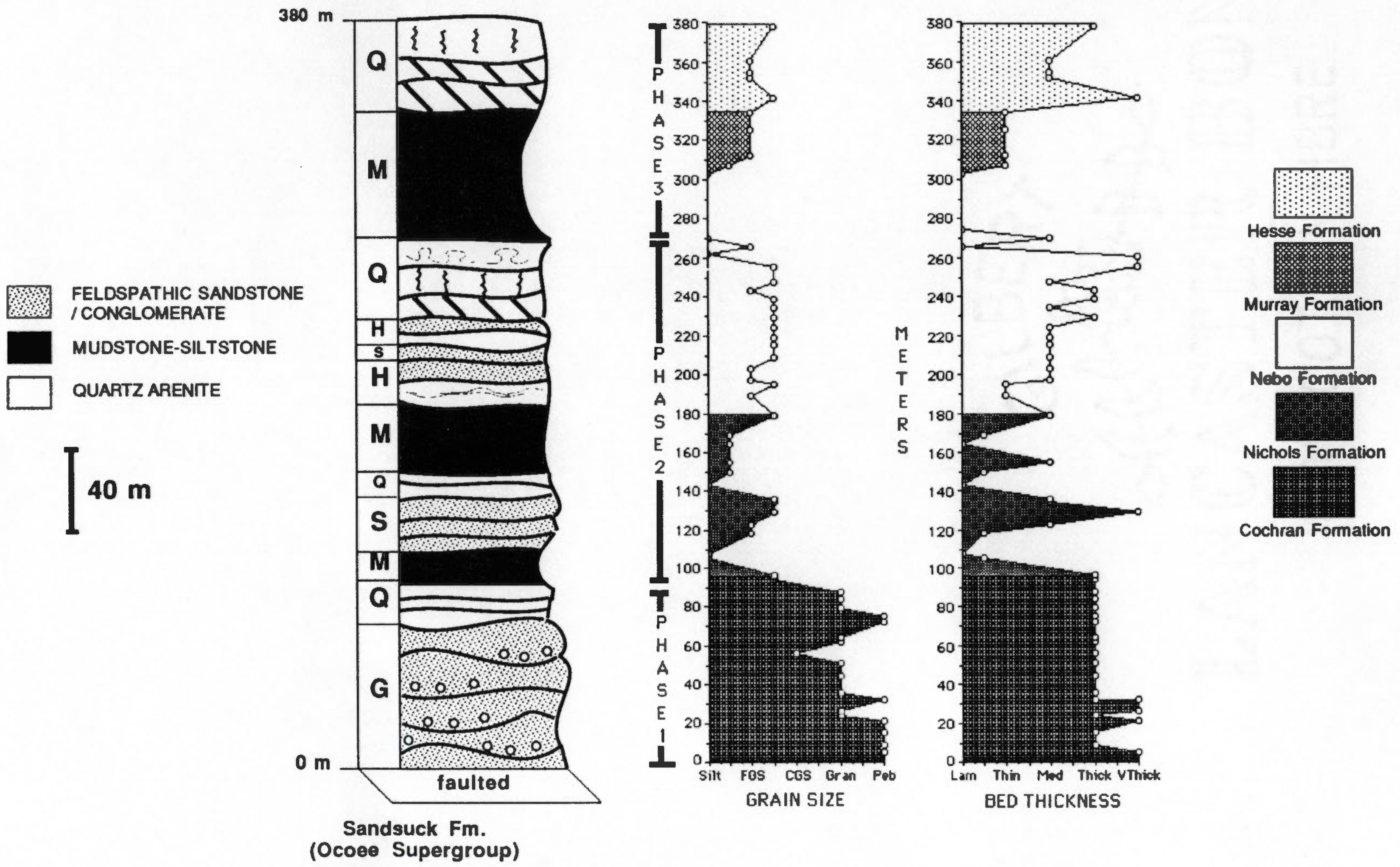

Mudstone-Siltstone Facies
FAIRWEATHER OUTER SHELF
Hummocky Facies
STORM DOMINATED SHELF
Upper Quartz Arenite Facies
SUBTIDAL SAND RIDGE
Sandstone Facies
SUBTIDAL CHANNELS AND SHOALS
Lower Quartz Arenite Facies
RIDGE AND RUNNEL
Conglomerate Facies
Large-scale, Planar-tabular Variant Dominant
DISTAL BRAIDED STREAM
Massive Variant Dominant
PROXIMAL BRAIDED STREAM

FIG. 3-15. - Depositional phases proposed for the Chilhowee Group at Chilhowee Mountain, Tennessee. Facies are labelled as follow: G = **Conglomerate** facies; M = **Mudstone - Siltstone** facies; S = **Sandstone** facies; Qa = **Quartz arenite** facies; and H = **Hummocky** facies.



FELDSPATHIC SANDSTONE / CONGLOMERATE
MUDSTONE-SILTSTONE
QUARTZ ARENITE
40 m
380 m
0 m
Q
M
Q
H
s
H
M
Q
S
M
Q
G
faulted
Sandsuck Fm. (Ocoee Supergroup)
PHASE 3
PHASE 2
PHASE 1
METERS
Silt
FGS
CGS
Gran
Peb
GRAIN SIZE
Lam
Thin
Med
Thick
VThick
BED THICKNESS
Hesse Formation
Murray Formation
Nebo Formation
Nichols Formation
Cochran Formation

shortly before the subsequent transgressive event, which marks the end of this phase of deposition. The two sequences which comprise this phase are defined by coarsening- and thickening upward trends (Fig. 3-15).

Depositional Phase 3 is the final phase of Chilhowee deposition as recorded at Chilhowee Mountain., and can again be characterized as an overall progradational event. This phase is represented by deposits of the mudstone-siltstone and sandstone facies, and comprises both the Murray and Hesse Formations. Again, the culmination of this phase is marked by a thick interval of *Skolithos* "pipe-rock" of the upper quartz arenite facies. Unlike the previous phases, it's end is marked by a transition to stable margin carbonate deposition (Shady Dolomite) rather than by a rapid transgressive event. This sequence of depositional phases then establishes a time reference frame for the reconstruction of the depositional system for all of the sections under discussion.

Phase 1 (Cochran - Unicoi Time)

The widespread distribution of variants of the conglomerate facies indicates that an extensive braided alluvial stream/plain system was established across the entire region. A system of shoals or bars and channels existed seaward of the shoreline, as evidenced by the association of sandstone and lower quartz arenite facies with the conglomerate facies. The mesotidal shore of Skeiderasandur, Iceland may represent a modern analogue for this system (Hine and Boothroyd, 1978). This storm-dominated, high fluvial-sediment-discharge coastline conspicuously lacks features associated with barrier islands (e.g., recurved spits, tidal deltas, lagoons and estuaries). River flooding hinders the formation of wide barrier spits. Seaward of these restricted spits is a system of ridges and offshore bars.

Phase 2 (Nichols-Hampton / Nebo time)

The distribution of facies indicate that the relative positions of each section during this interval are consistent with those inferred for Phase 1. The entire region experienced an initial rapid transgressive event followed by progradation of proximal marine environments over more distal marine environments. The migration of a shoreface - tidal-channel - shoal setting into a deeper-water, outer-shelf setting resulted in deposition of two distinct progradational packages at Chilhowee and Bean Mountains. The earlier of these two events is not recorded at Valley Forge, indicating that the second progradation was of a lesser magnitude. Its extent at Chilhowee Mountain is likewise restricted, as it occupies a thinner stratigraphic interval.

The transition between the two phases, corresponding to the Cochran-Unicoi / Nichols-Hampton contact, formed when wave processes no longer dominated, and tidal process became equally important. Consequently the relative abundance of the sandstone versus lower quartz arenite facies increased. This overall transition may have resulted in a change of depositional patterns. Resulting is a system similar to that documented in the German Bight of the North Sea (Reineck and Singh, 1980). In this area shoreface bars and channels are oriented parallel to longshore currents rather than possessing a distinct orientation with respect to shoreline.

Phase 3 (Murray / Hesse Time)

Once again, the base of this interval is marked by a rapid transgressive event which affected the entire region. The initial deeper-water conditions prevalent on the shelf resulted in wide-spread fairweather sedimentation of mud- and siltstone. This depositional pattern was periodically interrupted by storm-induced sandstone deposition as well as the widespread migration of sand ridges. These sand ridges moved in response to tidally-enhanced storm currents. The shelf must then have been hydraulically segregated into areas consisting of large sand ridges, patches of megarippled sand, and areas receiving coarser sediment only during storm events.

The North Sea (Houbolt, 1968) and the Celtic Sea (Belderson and Stride, 1966), appear to be analogous. These areas possess sand ridges, which are separated by expanses of mud and silt deposited below fairweather wave base. Storm events may then result in the emplacement of storm-sand beds which are sourced by the ridges.

SUMMARY

The Chilhowee Group (uppermost Proterozoic to Lower Cambrian) of East Tennessee, is an overall transgressive sequence, deposited on the stabilizing passive continental margin which formed during the inception of the Iapetos ocean. Examination of 5 sections of the Chilhowee Group at Bean Mountain (southeastern Tennessee), Chilhowee Mountain (east-central Tennessee), English Mountain and along Interstate 40 near Newport (east-central Tennessee), and near Valley Forge (northeastern Tennessee), resulted in the identification of six major facies (Table 3-1). These facies include:

1) the conglomerate facies (braided stream deposition);
  - massive variant
  - large-scale, planar-tabular variant
  - megarippled variant
  - laminated sandstone variant
2) the interlaminated mudstone-sandstone facies (lacustrine deposition);
3) the sandstone facies (subtidal channel and shoal deposition);
4) the quartz arenite facies (subtidal ridge and ridge and runnel deposition);
  - lower variant
  - upper variant
5) the hummocky facies (storm shelf deposition);
6) the mudstone-siltstone facies (fairweather shelf deposition).

The regional and stratigraphic occurrence of each of these facies and their variants allow for the formation of several conclusions:

I) The vertical arrangement of these various facies delineates three major phases of sedimentation (Fig. 3-15).

PHASE 1 - braided stream - lacustrine - alluvial plain sedimentation.

PHASE 2 - rapid transgression, followed by progradation of shoreface and inner shelf environments into an outer shelf environment dominated by fairweather mud and silt deposition.

PHASE 3 - rapid transgression, followed by progradation of shoreface and inner shelf environments into an outer shelf environment dominated by fairweather mud and silt deposition.

This overall transgressive sequence is capped by a final interval reflecting starved-shelf conditions, which heralded the initiation of carbonate platform sedimentation.

I) Each of the these sections represents deposition at various positions within the depositional system, which can be characterized with respect to paleoshoreline: I-40 (most proximal), Valley Forge, Chilhowee Mountain, and Bean Mountain (most distal; Fig. 3-13).

II) The variation in the palinspastic versus present day positions of each of the three sections discussed reflects:

1) variation in the amount of tectonic transport experienced by the Holston Mountain thrust sheet (Doe River section) versus the Great Smoky thrust sheet (Bean Mountain and Chilhowee Mountain sections).

2) divergence between structural and depositional strikes

3) influence of local promontories and embayments in the Iapetos margin.

CHAPTER 4

PALEOTECTONIC SIGNIFICANCE OF THE QUARTZITE OF THE SAURATOWN MOUNTAINS WINDOW, NORTH CAROLINA

INTRODUCTION

Quartzite exposed at Pilot Mountain, Pilot Mountain State Park, North Carolina, represents the westernmost exposure of a locally extensive quartzite body that is part of a metasedimentary sequence termed the "Sauratown formation" by McConnell (1988) or part of the Hogan Creek Formation of Hatcher and others (1984). This sequence rests on Middle Proterozoic (1.0 to 1.2 Ga) basement (Rankin and others, 1973; McConnell and others, 1986), which lies within the core of a broad anticlinorium (Butler and Dunn, 1968). This basement and the associated cover sequence are exposed in the Piedmont by the Sauratown Mountains window (Hatcher, 1987; Hatcher and others, 1988) and, with the Pine Mountain belt of Alabama and Georgia, and the State Farm Gneiss of Virginia (Farrar, 1984), constitute the easternmost internal basement massifs of the southern Appalachian orogen (Fig. 4-1; Hatcher, 1984). These basement massifs occur immediately west of the low to high gravity gradient inferred to represent the eastern edge of Grenville crust (Williams, 1978; Hatcher and Zietz, 1980; Haworth and others, 1981; Hatcher, 1984). These massifs, then, probably represent parautochthonous basement exposed beneath the main thrust sheet (Hatcher, 1984; Fig. 4-2).

The first suggestion that the Sauratown formation and the underlying basement were exposed within a window through the Inner Piedmont belt was made by Bryant and Reed (1961), on the basis of lithologic and stratigraphic similarities of the cover sequence to North American passive margin sediments of the Chilhowee Group (latest Proterozoic to Early Cambrian) rocks exposed within the Grandfather Mountain window (western North Carolina) and the Unaka belt (northeasternmost Tennessee). The regionally restricted nature of the quartzite of the Sauratown formation as well as its association with equally restricted basement has prompted workers to postulate that the quartzite represents deposition on a isolated basement horst (Rankin, 1975) or continental fragment rifted

FIG. 4-1. - Map of southern and central Appalachians showing main structural elements and distribution of Grenville basement rocks (black), GFW = Grandfather Mountain window. Modified from Hatcher, 1984).

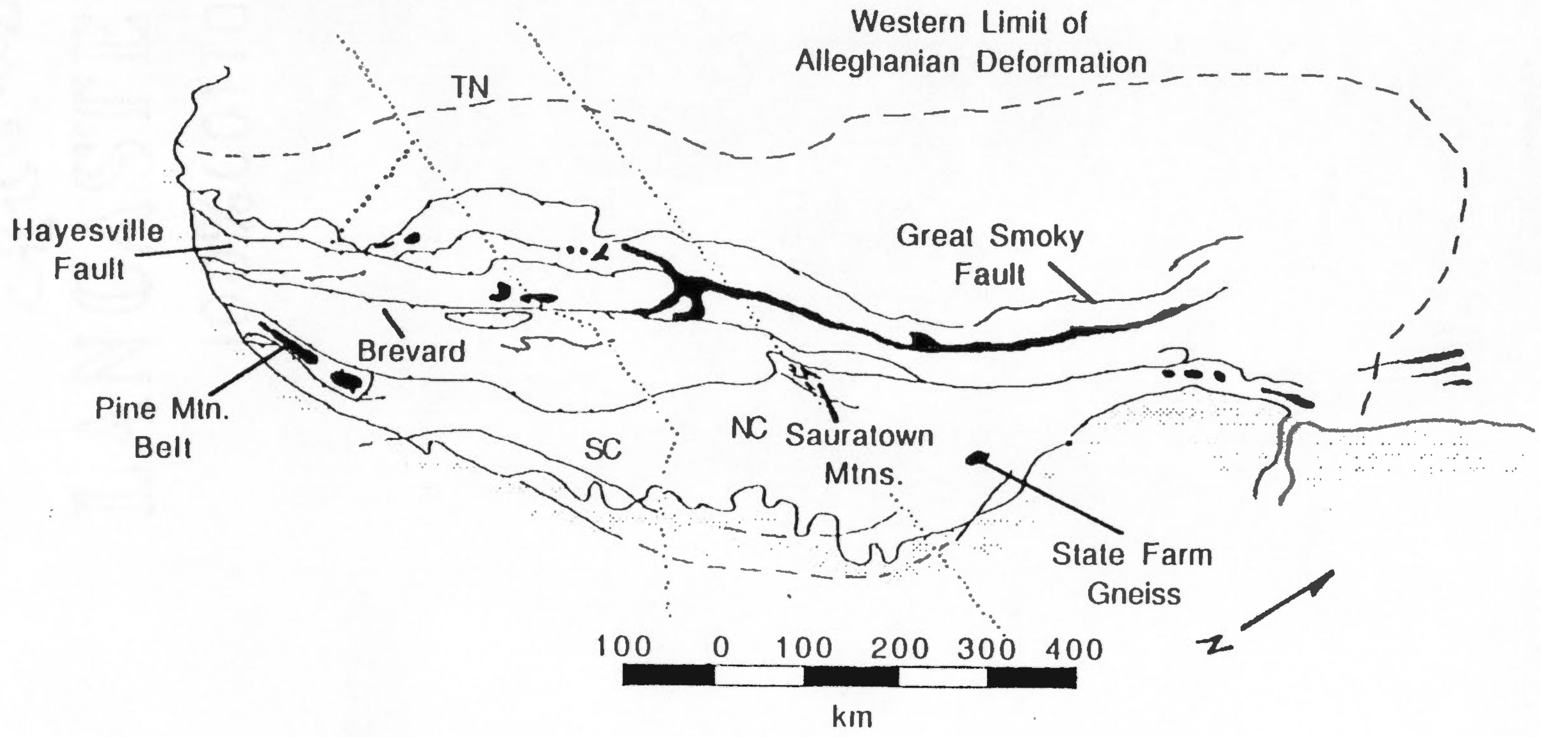
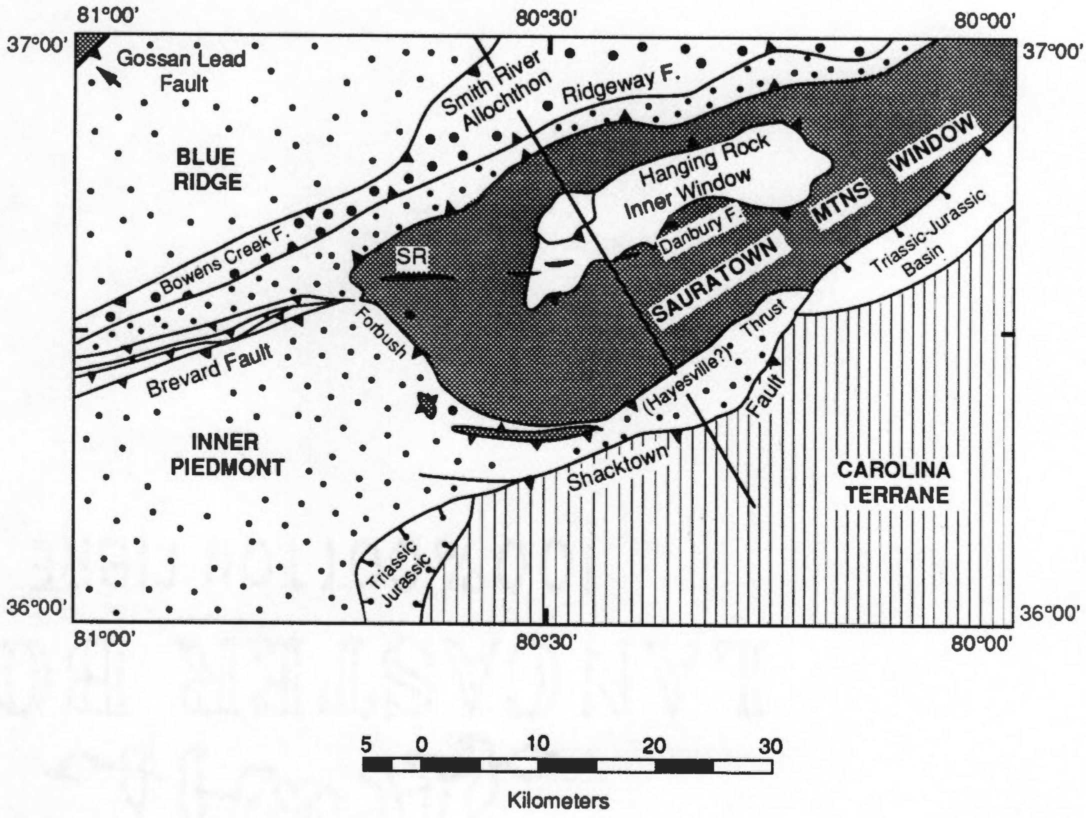
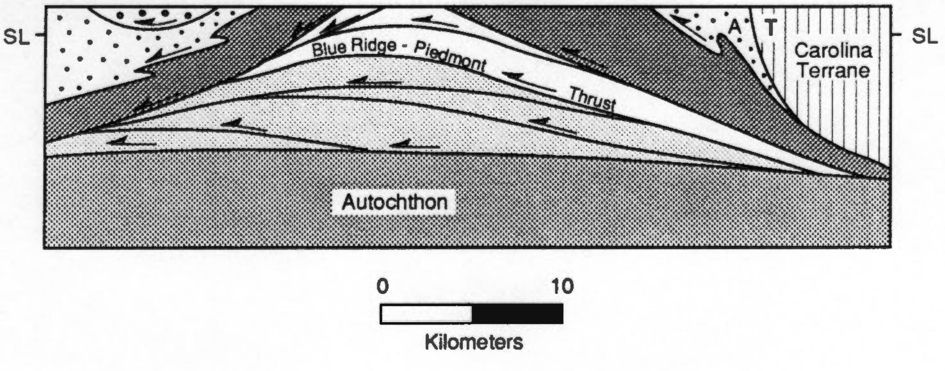

Western Limit of
Alleghanian Deformation
TN
Hayesville
Fault
Great Smoky
Fault
Brevard
Pine Mtn.
Belt
SC
NC
Sauratown
Mtns.
State Farm
Gneiss
N
100 0 100 200 300 400
km

FIG. 4-2. - Geologic map and cross-section of Sauratown Mountains window. From Hatcher (1988).


81°00'
80°30'
80°00'
37°00'
37°00'
Gossan Lead Fault
Smith River Allochthon
Ridgeway F.
BLUE RIDGE
Hanging Rock Inner Window
WINDOW
MTNS
Danbury F.
SAURATOWN
Triassic-Jurassic Basin
Bowens Creek F.
SR
Forbush
Brevard Fault
Thrust
(Hayesville?)
Fault
INNER PIEDMONT
Shacktown
CAROLINA TERRANE
Triassic Jurassic
36°00'
36°00'
81°00'
80°30'
80°00'
5 0 10 20 30
Kilometers


SL
SL
A
T
Carolina Terrane
Blue Ridge - Piedmont
Thrust
Autochthon
0 10
Kilometers

from the continent but left as a microcontinent within the Iapetos ocean basin (Thomas, 1977; Fig. 4-3). Subsequent mapping of the area has confirmed the existence of the Sauratown Mountains window (Hatcher, 1988; Heyn, 1988; McConnell, 1988) and suggests the broad anticlinorium may be related to duplex thrusting beneath the Blue Ridge - Piedmont (BRP) thrust sheet (Fig. 4-2). Palinspastic restoration of the BRP thrust sheet (Hatcher, in press) places the quartzite of the Pilot Mountain area 60-80 km east of its present position and therefore occupied a position 50 - 60 km oceanward of the Late Proterozoic continental margin as represented by the regional gravity gradient. Correlation of the quartzite of the Sauratown formation with Late Proterozoic rift facies sediments (Tallulah Falls - Ashe Formation) or Early Cambrian passive margin sediments (upper portion of Chilhowee Group) would not affect the location of the quartzite in the reconstruction.

Inner Piedmont rocks in the area are typically assigned to the upper amphibolite facies (sillimanite grade; Conley, 1978) metamorphic grade decreases to greenschist facies within the central part of the Sauratown Mountains window (McConnell, 1988). In addition, mapping in the region adjacent to Pilot Mountain (Hatcher, 1988; Heyn; 1988; McConnell, 1988) has resulted in the identification of at least three major fold generations. Despite extensive deformation and metamorphism, the quartzite displays a diverse array of well-preserved, primary sedimentary features that permit detailed facies analysis (Table 4-1). Comparison of the quartzite exposed at Pilot Mountain with similar sedimentary facies of the Chilhowee Group of East Tennessee presented here, indicates that these two stratigraphic sequences represent sediments shed from similar, yet geographically separate source terranes This conclusion would strongly support previous interpretations in which the Middle Proterozoic basement exposed within the Sauratown Mountains window represents a rifted fragment of continental crust that formed a microcontinent in the opening Iapetos ocean (Thomas, 1977).

METHODS

The nature of exposure at Pilot Mountain dictates that examination of the quartzite body be limited to traverses along the cliff base; there are few vertical sections observable. Hiking trails maintained by park staff provide access to varying stratigraphic levels within the quartzite body. Regional deformation in the area has resulted in varying degrees of

FIG. 4-3. - Laurentian - Iapetos margin morphology during Late Proterozoic to Early Cambrian time. Modified from Thomas (1977)

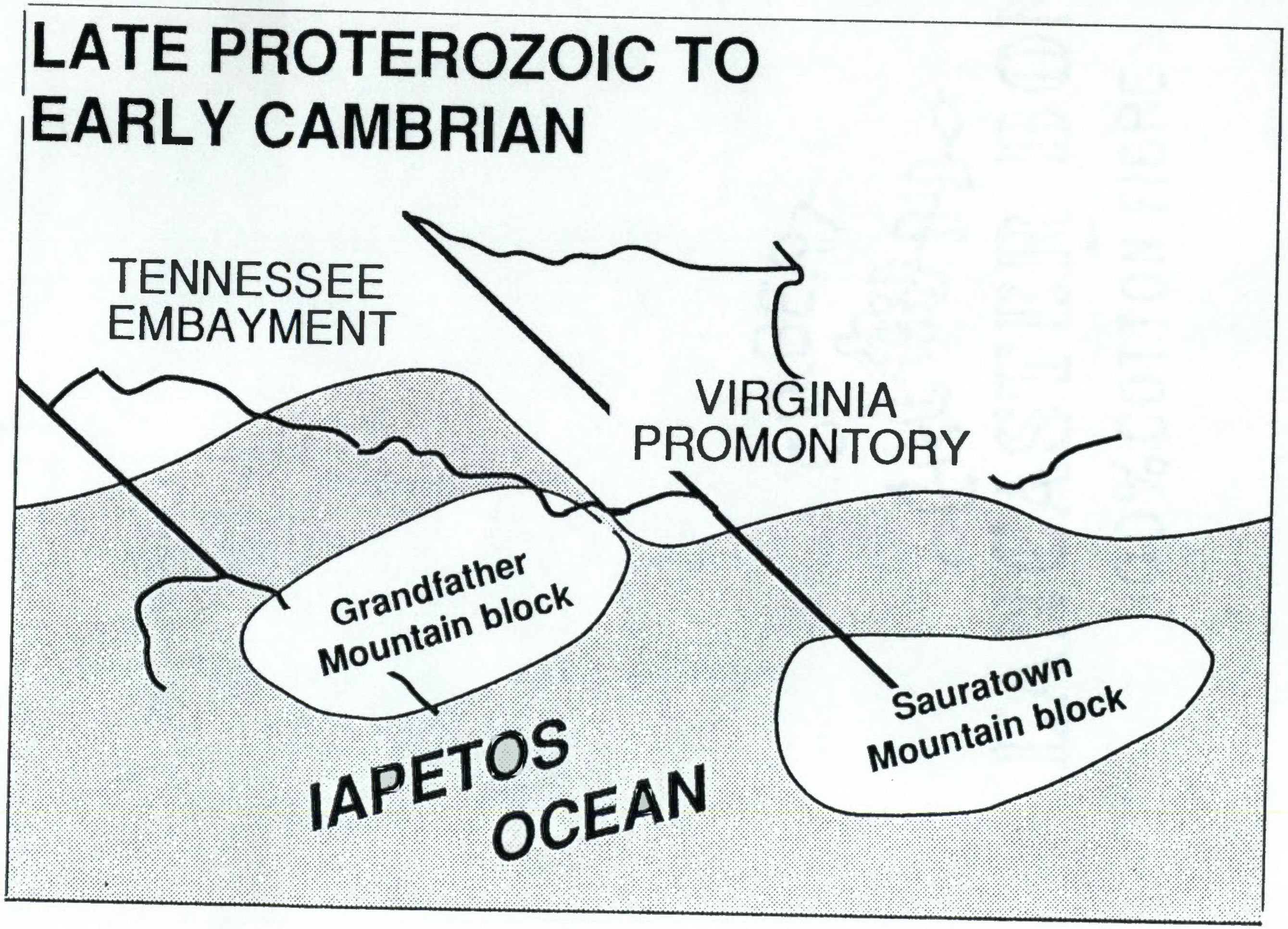

LATE PROTEROZOIC TO
EARLY CAMBRIAN
TENNESSEE
EMBAYMENT
VIRGINIA
PROMONTORY
Grandfather
Mountain block
Sauratown
Mountain block
IAPETOS
OCEAN

TABLE 4-1. - *Facies description and interpretation*

Facies	Description	Depositional Process / Environment	Environmental Analogue
Low-angle, planar-tabular cross-stratifed facies	0.1-0.3 m thick beds displaying low-angle (2-10^{o})dipping lamination (marked by heavy mineral concentration) oriented in a variety of directions resulting in characteristic "wedge" cross-stratification.	Produced by swash and backswash in the **foreshore** zone of high energy marine coastline.	Modern high energy coast of Oregon (Clifton and others, 1971).
Trough cross-stratifed facies	0.3-1.0 m thick beds displaying small-scale trough and planar-tabular cross-stratification. Individual beds possess planar bases and tops (Fig. 4-3b + 4-3C).	Produced by the migration of 3-D and 2-D ripples or dunes under unidirectional flow associated with wave surge and wave-generated currents in a **upper shoreface** setting.	Upper Cretaceous Gallup Sandstone of New Mexico (Harms and others, 1982).
Interbedded sandstone and "shale" facies	0.1 - 0.3 m thick beds of quartz sandstone, displaying a variety of primary stratification (horizontal lamination, small-scale trough and planar-tabular cross-stratification) interbedded with shale (preserved as phyllite; Fig. 4-3D).	Produced by migration of 3-D and 2-D bedforms under varying flow conditions during fair-weather and storm deposition in a **lower shoreface** to **inner shelf** setting.	Lower Cretaceous Carolinefjellet Formation of Spitsbergen (Nøttvedt and Kriese, 1987).

recrystallization and penetrative deformation as well as extensive isoclinal folding (Fig. 4-4). Consequently, some parts of the quartzite body are devoid of primary sedimentary structures and attempts to measure and describe an accurate stratigraphic section were severely hampered. Furthermore, although some possible paleocurrent indicators were available, uncertainties in the amount of structural rotation experienced by each precluded their use with any degree of reliability. As a result of numerous traverses, more than 25 m of the estimated 45 m of quartzite were examined (Fig. 4-5). The section described here therefore represents a composite section based on the relative position of various sedimentary structures and suites of structures observed in the quartzite body.

DEPOSITIONAL SETTING

The vast majority of the quartzite can be characterized as a well-sorted, mineralogically mature fine- to medium-grained quartz sandstone; laminations within individual beds are well defined by heavy mineral concentrations. Consequently, examination of exposures at Pilot Mountain resulted in the identification of a broad range of primary sedimentary structures and cross-stratification types. Facies definitions are based on the suite of primary sedimentary structures and stratification types present, as well as the stratigraphic occurrence of these features. Three facies were defined and include: 1) the low-angle, planar-tabular cross-stratified sandstone facies; 2) the trough cross-stratified sandstone Facies; and 3) the interbedded sandstone and shale (phyllite) facies (Table 4-1, Fig. 4-4).

The textural and mineralogic maturity of the deposits, as well as the concentrations of heavy minerals, suggest a high degree of reworking within a fairly high energy environment. Several of the cross-stratification types observed are indicative of deposition by oscillatory flow, suggesting subaqueous deposition. The overall distribution of primary features further suggests that the bedforms produced formed under varying components of both unidirectional (current) and oscillatory (wave) flow. Trace and body fossils were not observed within the quartzite. However, due to the locally pervasive nature of deformation and the non-uniform distribution of Early Cambrian fossils in coeval sequences (Crimes, 1987; see Chapter 2 for more discussion), their absence cannot be construed as indicating pre-Late Proterozoic (pre-Vendian) or nonmarine deposition. As can be seen in Figure 4-4, the apparent stratigraphic

FIG. 4-4. - Diverse array of primary cross-stratification types observed within quartzite at Pilot Mountain, Surry County, North Carolina. Lens cap for scale measures 16 cm in diameter. A= Intensely folded fine-grained layer interstratified with quartzite displaying well preserved primary sedimentary structures. B = Small scale, high-angle, planar-tabular cross-stratification. Note "pseudo-piperock" texture in right margin of photo. C = Small-scale trough cross-stratification. D = Composite bed composed of small-scale, high-angle, planar-tabular cross-stratification (base) and small-scale trough cross-stratification (top).

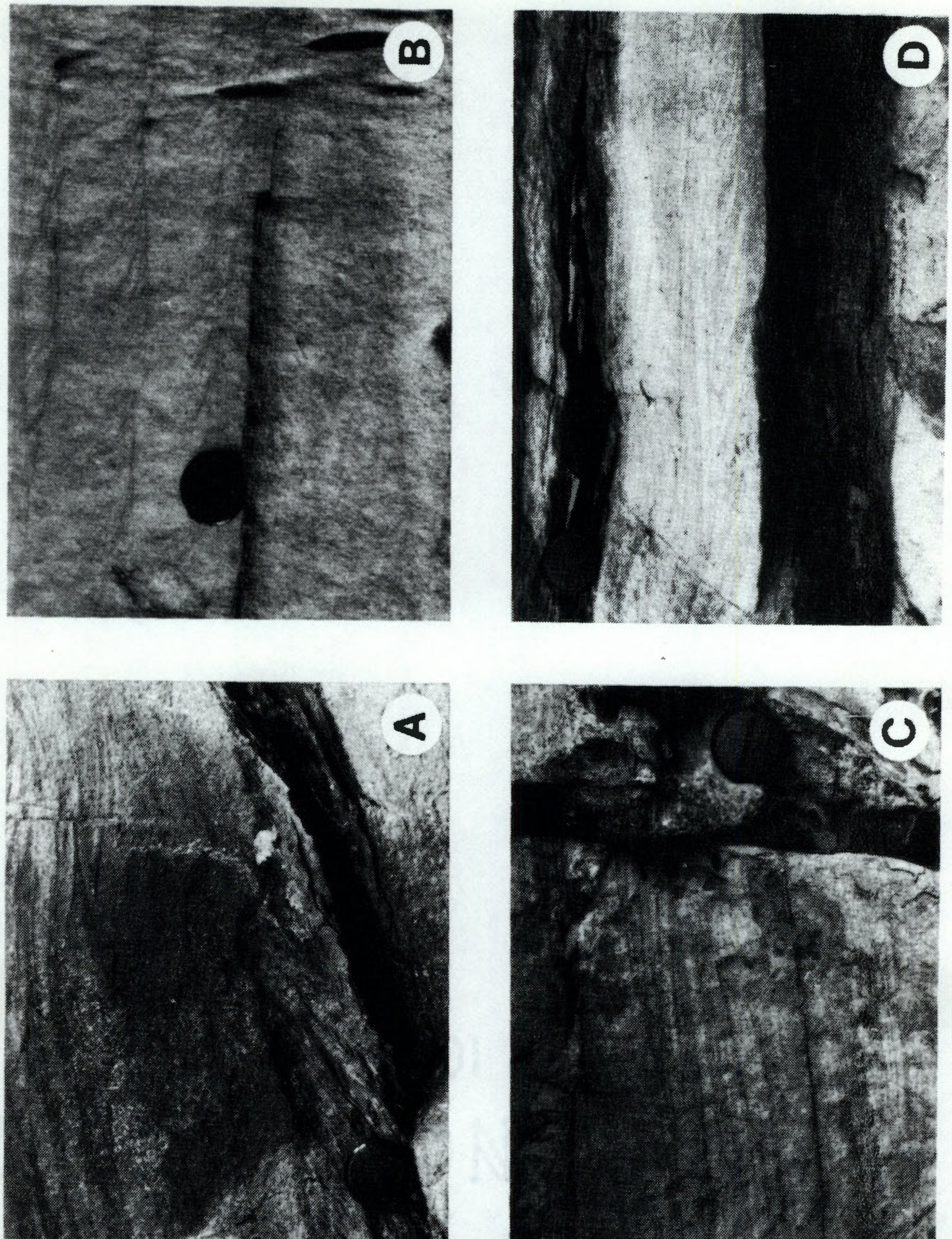
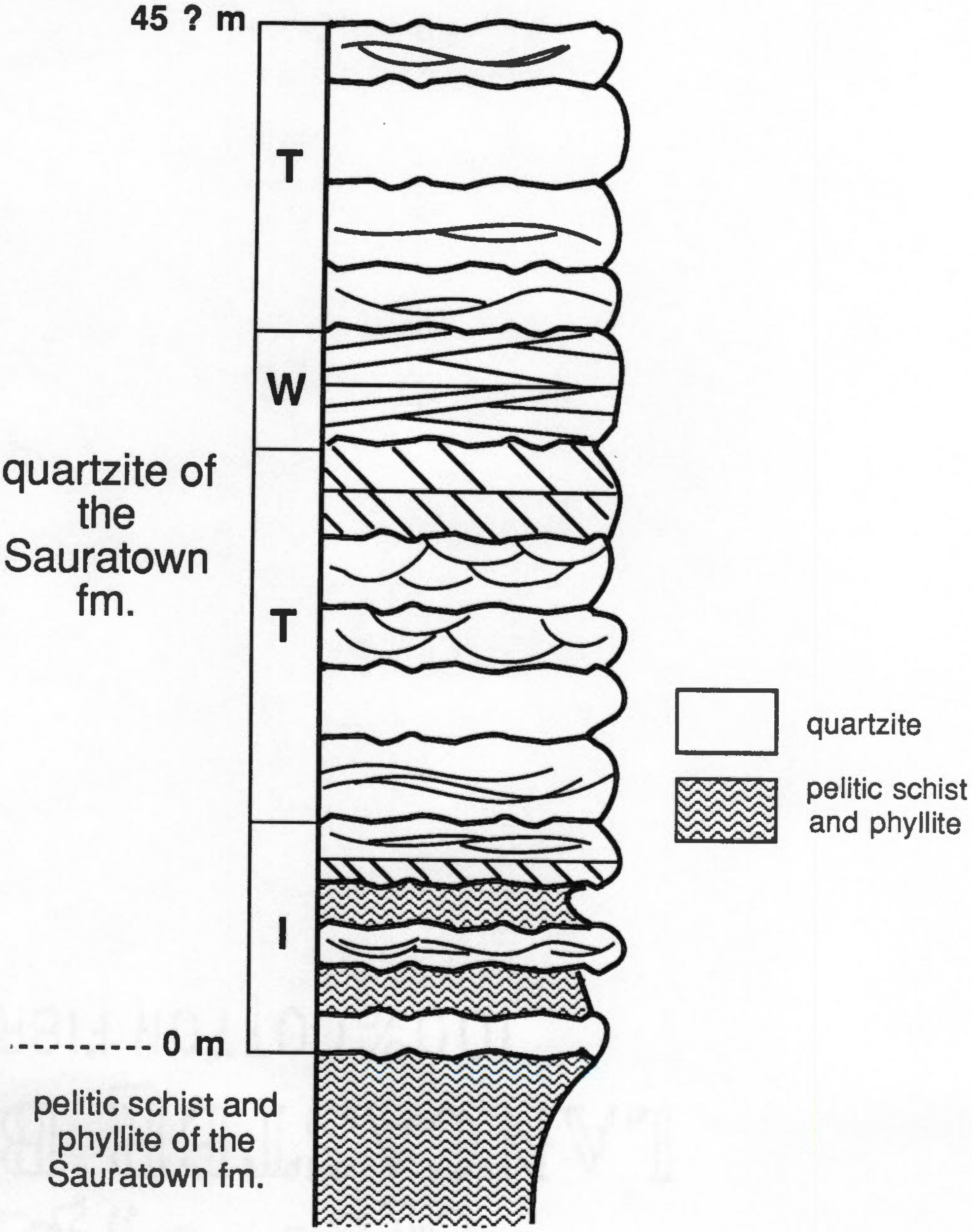

A
B
C
D

FIG. 4-5. - Composite (see text for explanation) stratigraphic section for quartzite at Pilot Mountain, North Carolina. I = interbedded sandstone and "shale" facies, T = trough cross-stratified facies, and W = low-angle, planar-tabular (wedge) cross-stratified facies. Vertical scale in meters.


45 ? m
T
W
T
I
0 m
quartzite of the Sauratown fm.
pelitic schist and phyllite of the Sauratown fm.
quartzite
pelitic schist and phyllite

arrangement of the facies (Table 4-1) exposed at Pilot Mountain indicates deposition in a shallow shelf to foreshore (beach) setting during some fluctuation of relative sea level. The quartzite can then be separated into two depositional phases, the lower phase representing a typical progradational sequence, and the upper representing sedimentation during transgression.

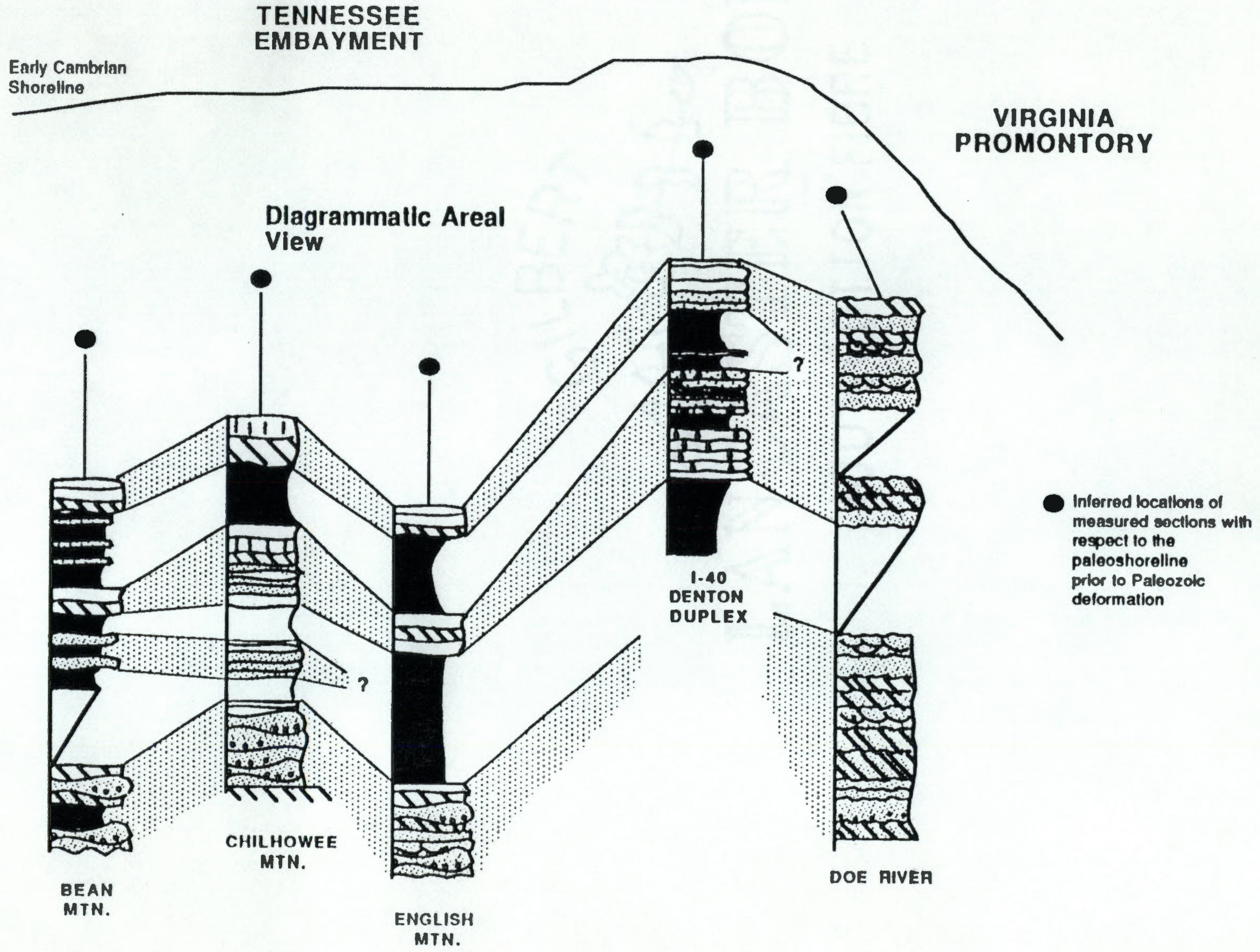
COMPARISON WITH CHILHOWEE GROUP OF EAST TENNESSEE

The Chilhowee Group (uppermost Proterozoic to Lower Cambrian; see Chapter 2 for more discussion) is a 600-1200 m thick terrigenous clastic sequence of interbedded feldspathic and lithic conglomerate, feldspathic and quartz arenite, siltstone, and shale that crops out in narrow belts along the western margin of the Blue Ridge province and immediately adjacent thrust belts of the Valley and Ridge province (Schwab, 1972; Whisonant, 1974; Mack, 1980). The northeast-southwest trending outcrop extends along strike from Alabama to Newfoundland. In East Tennessee the Chilhowee Group is composed of several stratigraphic units interpreted as representing fluvial and marine sedimentation in a range of depositional settings from coastal braid plain to outer shelf. Detailed examination of Chilhowee Group strata at a number of localities led to the identification of several sedimentary facies which can be used to elucidate the regional paleogeographic setting (Fig. 4-6).

Examination of the available structural data (Fig. 4-7) as well as the distribution of facies described above suggest that present day structural strike in the area does not coincide with the latest Proterozoic to Early Cambrian depositional strike. Trends in proximality (with respect to the craton) can be characterized as representing both a northwest to southeast gradient, *and* a northeast to southwest gradient (Fig. 4-6). This geometry is consistent with previous suggestions (Rankin, 1975, 1976; Thomas, 1977, 1983) that the southern strike belts (Bean Mountain and Chilhowee Mountain) occupied a position within an embayment, while the northeastern strike belts (I-40, English Mountain, and Valley Forge localities) occupied a position adjacent to or within a promontory (Tennessee embayment and Virginia promontory, respectively; Thomas, 1983).

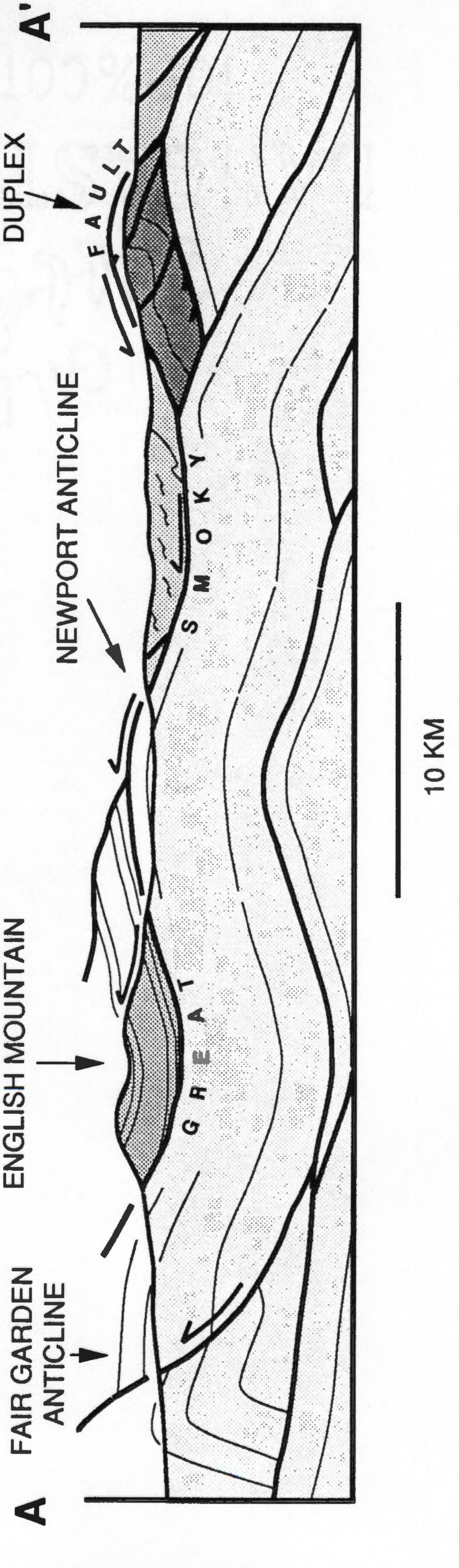
A process-oriented sedimentologic study was conducted on the Chilhowee Group of the Unaka belt at the Valley Forge locality by Cudzil (1985) along U.S. Highway 19E

FIG. 4-6. - Inferred palinspastic locations of Chilhowee Group sections in East Tennessee. Restored locations based on proximality of facies and structural data.



TENNESSEE EMBAYMENT
Early Cambrian Shoreline
VIRGINIA PROMONTORY
Diagrammatic Areal View
?
?
BEAN MTN.
CHILHOWEE MTN.
ENGLISH MTN.
I-40 DENTON DUPLEX
DOE RIVER
Inferred locations of measured sections with respect to the paleoshoreline prior to Paleozoic deformation

FIG. 4-7. - Geologic cross-section constructed from English Mountain southeast through the Denton Duplex. Note the inferred tectonic transport along Great Smoky fault placing the English Mountain locality cratonward of the I-40 locality (Denton Duplex). Mapping and cross-section completed by Robert (1987). Figure modified from Robert (1987).


A'
DENTON DUPLEX
FAULT
NEWPORT ANTICLINE
SMOKY
ENGLISH MOUNTAIN
GREAT
FAIR GARDEN ANTICLINE
A
10 KM

southeast of Elizabethton, Tennessee, nearly 150 km west of Pilot Mountain, North Carolina. Study of exposures at the Valley Forge locality resulted in the identification of four facies (Table 4-1) that were interpreted as representing deposition within environments ranging from coastal, alluvial braided plain to outer shelf (Cudzil and Driese, 1987). The shallowest of the marine environments was represented by supermature quartz arenites possessing low-angle cross-stratification and large-scale planar-tabular cross-stratification similar to that observed in the quartzite of Pilot Mountain. At Valley Forge, the thickest mature marine quartz sandstone body within the Chilhowee Group measures less than 40 m. If the observed change in proximality, represented by thinning of quartz sand bodies to the east, are valid (see Chapter 3 for more discussion) the apparent 40 m thickness of the quartzite at Pilot Mountain, more than 150 km to the east can be regarded as somewhat anomalous. The shallow-water nature of the quartzite at Pilot Mountain and the substantial thickness therefore suggests that it *does not* represent a distal equivalent of the Chilhowee Group exposed at Valley Forge, Tennessee. Because the Pilot Mountain quartzites occur east of two strike-slip faults of uncertain Alleghanian age dextral displacement (the Hayesville-Fries and Brevard; Edelman and others, 1987; Bobyarchick, 1988), their present geographic proximity to the Chilhowee Group of eastern Tennessee may be misleading. Examination of published work completed on more northern exposures of the upper Chilhowee Group in Virginia and Maryland indicate that these sequences probably represent more distal depositional settings than those inferred for coeval strata in eastern Tennessee (Schwab, 1972; Simpson, 1987; Simpson and Eriksson, 1990). The quartzites exposed at Pilot Mountain, North Carolina, are therefore even less likely to represent distal shelf equivalents of the Virginia and Maryland Chilhowee sequences.

DISCUSSION

Comparison of depositional processes and stratigraphic thicknesses of similar lithologies observed at Pilot Mountain and the Valley Forge locality do not appear to be consistent with the interpretation of the quartzite of Pilot Mountain as representing some eastern equivalent of the Chilhowee Group of the Unaka belt. The observed lithostratigraphic similarity between these two sequences may be a manifestation of similarities of source rock and depositional setting. Whereas chronostratigraphic equivalence may not be applicable, this type of similarity would be consistent with interpretation of the quartzite at Pilot Mountain as representing deposition along an offshore, rifted microcontinent or similar terrane, as proposed by Thomas (1977).

Because the entire Pilot Mountain sedimentary sequence rests on Grenville basement (Hatcher, 1984, 1987; Hatcher and others, 1988; McConnell and others, 1986), North American affinity appears certain. Palinspastic reconstruction of the southern Appalachian orogen indicates that the sedimentary sequences exposed within the Sauratown Mountains window, the Grandfather Mountain window, and the Unaka belt occupy the same *relative* positions (with respect to the North American continental margin) today as they did when they were first deposited. Therefore, two paleotectonic interpretations seem plausible:

1. The quartzite of the Sauratown Mountains window, North Carolina, represents Late Proterozoic (Tallulah Falls - Ashe Formation equivalent) deposition along a sea-floor high associated with an isolated basement terrane during early marine incursion into the late rift or early drift phase Iapetos basin, in a manner similar to that suggested for the Ocoee basin (Late Proterozoic) by Rast and Kohles (1986).

2. The quartzite of the Sauratown Mountains window, North Carolina, represent latest Proterozoic to Early Cambrian (Chilhowee Group time equivalent) deposition on an isolated, rifted continental fragment during the drift phase of the North American - Iapetos margin evolution.

In either instance, bathymetric shallowing along the flanks of basement block would result in the deposition of shallow-water sediments derived primarily from the rifted Grenvillian basement block as proposed by Thomas (1977; Fig. 4-3). During subsequent Paleozoic orogenic activity, the massif and cover probably served to localize thrusts, causing the finer-grained, offshore deposits of the Ashe Formation of the Blue Ridge - Piedmont thrust sheet to be ramped over and around (Hatcher, 1983; Hatcher and others, 1989; Fig. 4-2).

CHAPTER 5

SANDSTONE PETROLOGY OF THE BASAL CHILHOWEE GROUP (UPPERMOST PROTEROZOIC TO LOWERMOST CAMBRIAN): IMPLICATIONS FOR THE EVOLUTION OF THE LAURENTIAN - IAPETOS MARGIN, SOUTHERN APPALACHIANS

INTRODUCTION

Regional crustal extension responsible for the formation of the Iapetos (Proto-Atlantic) ocean is recorded by regionally discontinuous, yet widely distributed Upper Proterozoic siliciclastic and volcanic rocks of the southern Appalachian Blue Ridge province (Rankin, 1975, 1976; Thomas, 1977; 1983; Hatcher, 1978, 1987; Wehr and Glover, 1985). Because of the general lack of fossils within these non-marine, marine, and volcanic sequences, the exact chronologic relationships are poorly understood. A regional unconformity separates intrusive rocks within the Grenvillian basement of the Blue Ridge from the overlying Upper Proterozoic strata. These intrusive rocks comprise the Crossnore Plutonic Suite (a series of fluorite and sodic amphibole-bearing peralkline granites) which have yielded age dates of 690 $\pm$ 10 Ma (integrated Rb-Sr and U-Pb methods; Odom and Fullagar, 1984). These rocks predate actual rift-basin formation, as recorded by Upper Proterozoic strata (e.g., Ocoee Supergroup and Mount Rogers Formation), therefore their age can be taken as a maximum age for regional extension.

The transition from continental rift to passive margin during the evolution of the Laurentian - Iapetos margin in the southern Appalachians is generally accepted as being recorded by the Chilhowee Group (Upper Proterozoic to Lower Cambrian; Laurence and Palmer, 1963; Thomas, 1977, 1983; Hatcher, 1987, 1989; Simpson and Sundberg, 1987; see Chapter 2 for more discussion). The Chilhowee Group possesses a complex stratigraphic nomenclature and is exposed in a series of discontinuous strike belts from Alabama to Newfoundland (Figs. 5-1 and 5-2, Schwab, 1972; Mack 1980; Williams, 1978; Hatcher, 1989) and with few but significant exceptions is confined to the western Blue Ridge and the immediately adjacent portions of the Valley and Ridge. This study

FIG. 5-1 - Exposures of the Chilhowee Group (Upper Proterozoic to Lower Cambrian) and locations of measured sections. Modified from Schwab (1972) and Mack (1980).

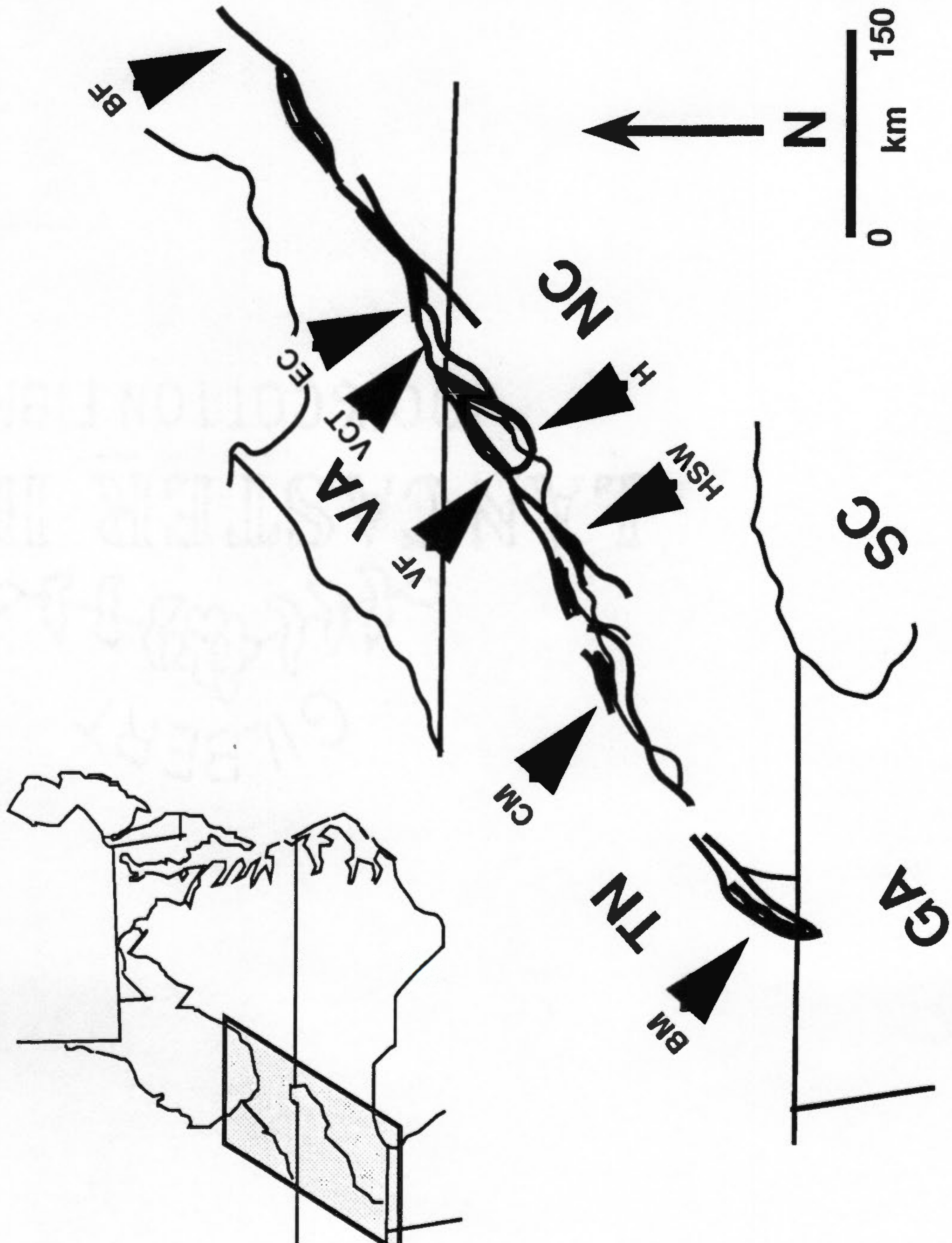

BF
EC
VCT
VF
H
HSW
CM
BM
VA
NC
SC
TN
GA
N
0
km
150

FIG. 5-2 - Chilhowee Group stratigraphy, Southern Appalachians. Modified from Mack, (1980) and Cudzil and Driese (1987).

<table>
<tr><th>AGE</th><th colspan="2">North Georgia and Alabama</th><th colspan="2">Southeastern Tennessee</th><th colspan="2">Hot Springs window, North Carolina</th><th colspan="2">Northeastern Tennessee</th><th>Southwestern Virginia</th><th>Northwestern Virginia</th></tr>
<tr><td rowspan="8">EARLY CAMBRIAN</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td colspan="2">Shady Dolomite</td><td>Shady Dolomite</td><td>Tomstown Dolomite</td></tr>
<tr><td rowspan="7">CHILHOWEE GROUP</td><td rowspan="2">Weisner Formation</td><td colspan="2">Helenmode Formation</td><td rowspan="4">Erwin Formation</td><td>Helenmode Member</td><td rowspan="4">Erwin Formation</td><td>Helenmode Member</td><td rowspan="4">Erwin Formation</td><td rowspan="4">Antietam Quartzite</td></tr>
<tr><td colspan="2">Hesse Quartzite</td><td>Hesse Quartzite Member</td><td>Hesse Quartzite Member</td></tr>
<tr><td rowspan="2">Wilson Ridge Formation</td><td colspan="2">Murray Shale</td><td>Murray Shale Member</td><td>Murray Shale Member</td></tr>
<tr><td colspan="2">Nebo Quartzite</td><td>Nebo Quartzite Member</td><td>Nebo Quartzite Member</td></tr>
<tr><td>Nichols Shale</td><td colspan="2">Nichols Shale</td><td colspan="2">Hampton Shale</td><td colspan="2">Hampton Shale</td><td>Hampton Shale</td><td>Harpers Formation</td></tr>
<tr><td rowspan="2">Cochran Formation</td><td colspan="2" rowspan="2">Cochran Formation</td><td colspan="2" rowspan="2">Unicoi Formation</td><td colspan="2" rowspan="2">Unicoi Formation</td><td rowspan="2">Unicoi Formation</td><td>Weaverton Quartzite</td></tr>
<tr><td>Loudon Formation</td></tr>
<tr><td>? PROTEROZOIC</td><td colspan="2">base of section always faulted out</td><td>Ocoee Supergroup</td><td>Sandsuck Formation</td><td>Ocoee Supergroup</td><td>Sandsuck Formation</td><td colspan="2">Mount Rogers Volcanic Group or Grenville basement</td><td>Mount Rogers Volcanic Group</td><td>Catoctin Greenstone or Swift Run Fm. or injection complexes</td></tr>
</table>

represents an attempt to document vertical and along-strike changes in the composition of sandstone deposited during the rift-to-passive margin transition of the Laurentian - Iapetos margin as exposed in East Tennessee, southwestern Virginia, and adjacent North Carolina. The compositional changes reveal significant variations in the tectonic history of the Chilhowee Group across the area and therefore have implications for the timing and nature of tectonism associated with the continental breakup of the Late Proterozoic supercontinent.

PALEOGEOGRAPHIC FRAMEWORK

Past studies of the Chilhowee Group provide the necessary data to construct the prerequisite paleogeographic framework in which sandstone composition may be used to elucidate tectonic history. These studies are numerous and include examinations of the regional stratigraphic patterns (Thomas, 1977; Mack, 1980), the sediment dispersal system and gross sandstone petrology (Schwab, 1972; Whisonant; 1970, 1974), and most recently, the evolving depositional systems via facies analysis (Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988; and Simpson and Eriksson, 1989; see Chapter 3 for more discussion).

Regional Stratigraphic Patterns

The regional distribution of Grenvillian basement and variation in sediment thickness described above, as well as later Paleozoic deformational patterns led Rankin (1975, 1976) and Thomas (1977, 1983) to propose that extension associated with the inception of the Iapetos ocean during the Late Proterozoic and Early Cambrian resulted in an irregular continental margin with associated isolated microcontinents (e.g., internal massifs of the Pine Mountain block and the Sauratown Mountain window; Thomas, 1977; Hatcher, 1987; Walker and others, 1989; Fig. 5-3; see Chapter 4 for more discussion). In the terminology proposed by Thomas (1983) the present-day recesses and salients recognizable in the map pattern of the Appalachian Orogen coincide with promontories and embayments (respectively) in the early Paleozoic Laurentian margin (Fig. 5-4). This paper deals with the morphology of the Laurentian - Iapetos margin and therefore the terms promontory (an angle or curve of the rifted margin concave cratonward) and embayment (an angle or curve of the rifted margin concave oceanward)

FIG. 5-3 - Simplified tectono-stratigraphic map of the U.S. Appalachian Orogen. Black areas denote exposure of Grenvillian basement (modified from Hatcher, 1989).

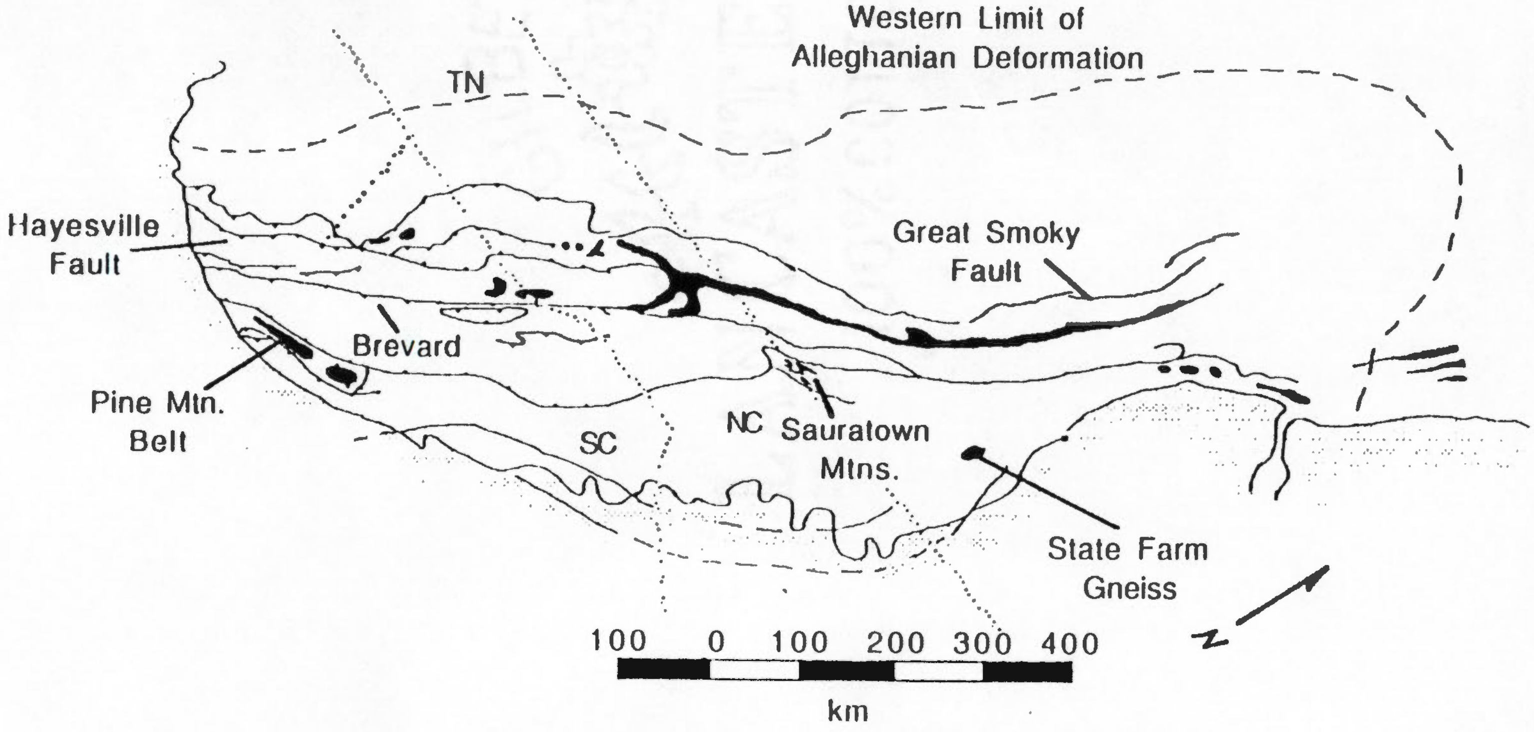
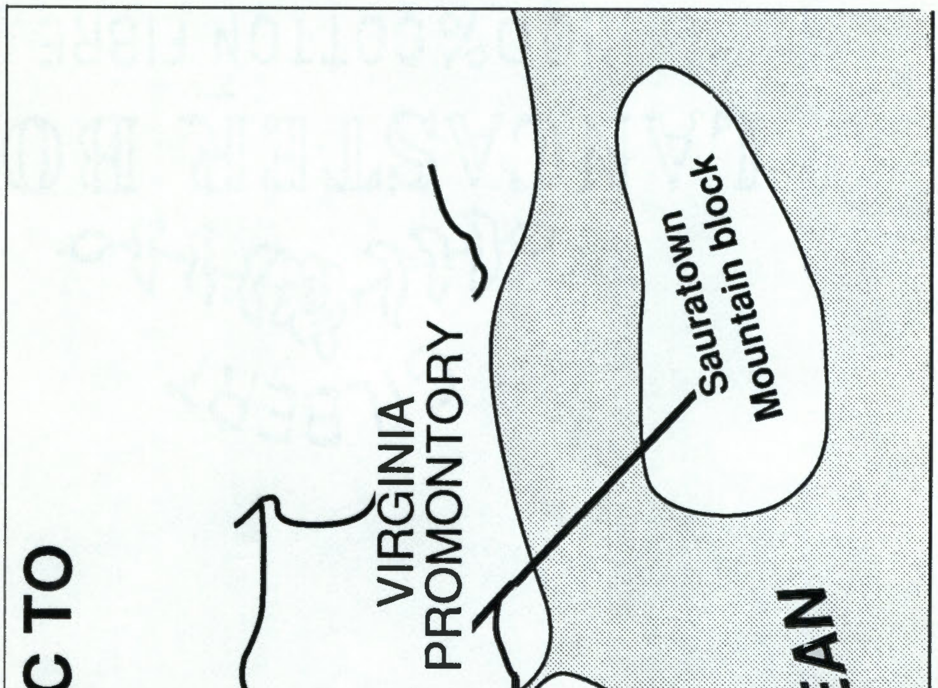

Western Limit of
Alleghanian Deformation
TN
Hayesville
Fault
Great Smoky
Fault
Brevard
Pine Mtn.
Belt
SC
NC
Sauratown
Mtns.
State Farm
Gneiss
N
100 0 100 200 300 400
km

FIG. 5-4 - Laurentian - Iapetos margin in the southern Appalachians during Late Proterozoic to Early Cambrian time. Modified from Thomas (1977) and Walker and others (1989).


LATE PROTEROZOIC TO
EARLY CAMBRIAN
TENNESSEE
EMBAYMENT
VIRGINIA
PROMONTORY
Grandfather
Mountain block
Sauratown
Mountain block
IAPETOS
OCEAN

will be used exclusively throughout (see Thomas, 1977, 1983 for further explanation). The dominant paleogeographic elements in the study area then include the Tennessee embayment and Virginia promontory (Fig. 5-4; Thomas, 1983). These elements mirror the southeastern limit of undeformed Grenvillian basement and are defined by the distribution of Upper Proterozoic rift-related strata of the Ocoee Supergroup and Mount Rogers Formation. The Cochran / Unicoi interval provides a reference to examine the temporal and spatial distribution of rifting across the entire area.

Ocoee Supergroup of the Tennessee embayment. The Ocoee Supergroup is a lithologically diverse assemblage of marine (dominant) and non-marine units exposed in the western Blue Ridge and may exceed 12 km in thickness (Hadley, 1970; Rast and Kohles, 1986; Fig. 5-5a). This sequence of Upper Proterozoic strata thus represents the basin fill of a Late Proterozoic rift basin that occupied a position within the Tennessee embayment (Thomas, 1977, 1983). A majority of the siliciclastic sediment preserved within the Ocoee Supergroup (especially the Great Smoky Group) was derived from Late Proterozoic Laurentian craton to the northeast (Thomas, 1977). The lowermost portion, however, (the Snowbird Group) was derived from continental blocks exposed to the east and southeast (Hadley and Goldsmith, 1963; Thomas, 1977; Rast and Kohles, 1986). Thomas (1977) proposed that this source terrane is represented by present-day exposures of Grenvillian granitic-gneissic basement of the eastern Great Smoky Mountains.

Amphibolites interpreted as metamorphosed mafic volcanic flows have been sampled within the lower portion of the Ocoee Supergroup near Ducktown, Tennessee. Geochemical analyses of these bodies have indicated that they possess relict trace element signatures similar to MORB basalts (Misra and Lawson, in press). Stratigraphically highest (and therefore youngest) of the groups comprising the Ocoee Supergroup is the Walden Creek Group. The Walden Creek Group has been described as the most heterolithic of all of the Ocoee Supergroup (Hadley and Goldsmith, 1963), containing greater than 3 km of dominantly siliciclastic strata. Minor limestone and dolostone intervals (Yellow Breeches member of the Wilhite Formation) may indicate relatively widespread if intermittent carbonate deposition (Hadley and Goldsmith, 1963). Directly above the Wilhite Formation are fine-grained siliciclastic deposits of the Sandsuck Formation (Hadley and Goldsmith, 1963). Late Proterozoic acritarchs have been recovered throughout the Walden Creek Group resulting in its assignment of a Vendian age (Knoll and Keller, 1979; see Chapter 2 for more discussion). Thus the overall stratigraphic architecture of the Ocoee may be interpreted as representing the evolution of a continental rift (Snowbird and Great Smoky Group deposits) to thermal subsiding basin (Walden Creek Group deposits).

Mount Rogers Formation and related strata of the Virginia promontory. The eastern limit of the Virginia promontory is defined as the western limit of Late Proterozoic siliciclastic and volcanic strata of the Mount Rogers and Grandfather Mountain Formations (Thomas, 1977). The Mount Rogers Formation exceeds 3 km in thickness and has been subdivided into three informal members on the basis of gross lithologic character (Fig. 5-5b, Rankin, 1967). These member include (from base to top): 1) a lower member, which is dominantly composed of polymictic conglomerate and graywacke deposits with minor intercalated rhyolite and basalt units; 2) a middle member, which is dominantly composed of felsic volcanic strata; and 3) an upper member which is composed dominantly of glaciogenic siliciclastic strata (Miller, J.M.G., pers. comm., 1989). The Mount Rogers Formation is readily interpreted as representing an active portion of the Late Proterozoic rift system (the Blue Ridge - Pine Mountain rift of Thomas, in prep).

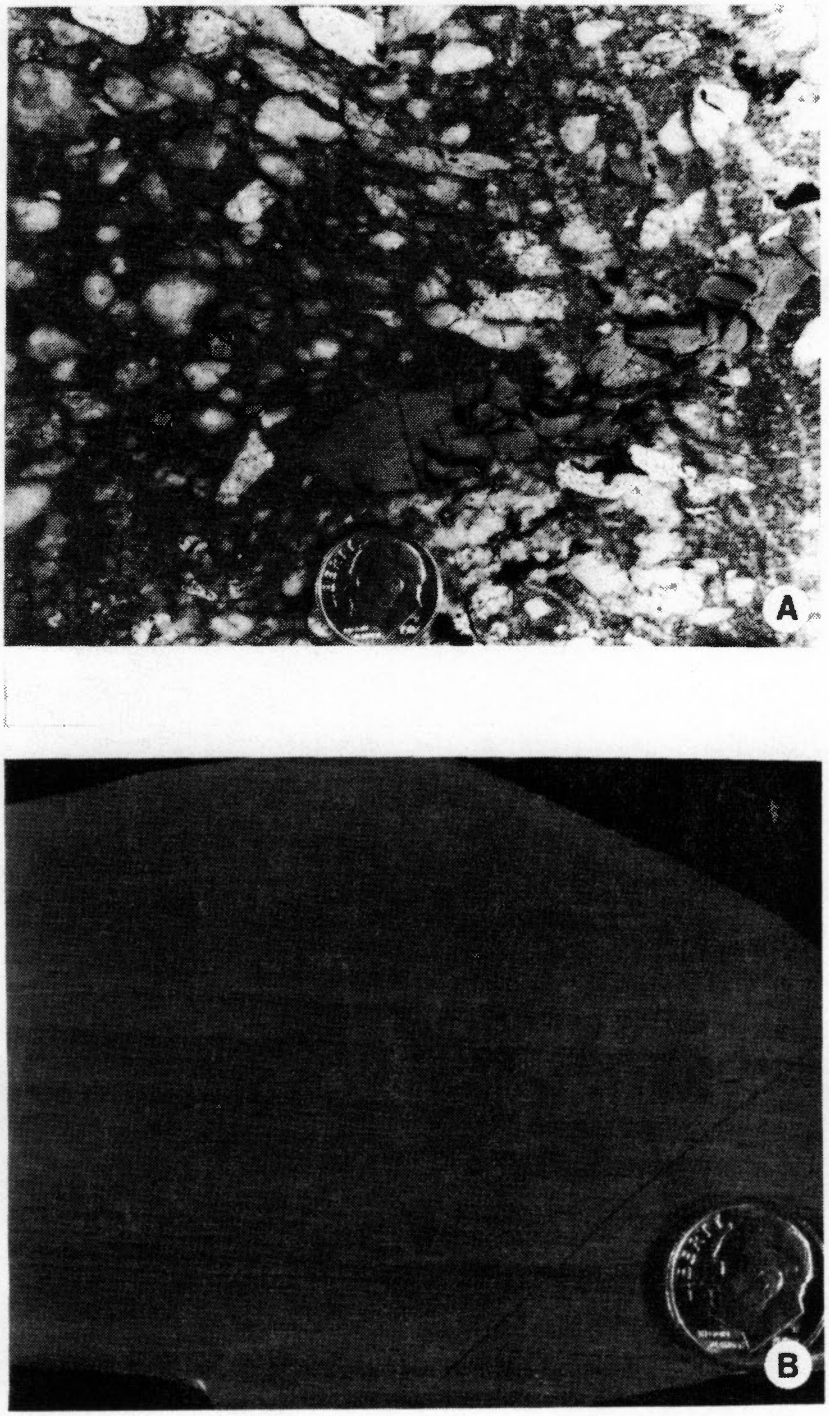
Chilhowee Group. The basal Chilhowee Group in the southern Appalachians is comprised of two coevally deposited and regionally distinct stratigraphic units termed the Cochran and Unicoi Formations. In southeastern Tennessee, the basal unit of the Chilhowee Group is a 100 - 200 m thick feldspathic conglomerate and pebbly sandstone and quartzose sandstone sequence termed the Cochran Formation (Rodgers, 1953). The Cochran Formation overlies the Sandsuck Formation of the Walden Creek Group (uppermost unit in the Ocoee Supergroup, Figs. 5-2 and 5-5a). Examination of the Sandsuck and basal Cochran at Bean Mountain showed the Formations to be in depositional contact (Skelly, 1987). This contact becomes erosive to the northeast where the basal conglomerates of the equivalent Unicoi Formation contain shale clasts identical to the underlying Sandsuck lithologies (Fig. 5-6). This apparent erosional relationship has prompted many workers to describe the entire basal Chilhowee / Sandsuck contact as disconformable and therefore representing a break-up unconformity (Wehr and Glover, 1985). The apparent transition from conformable relationship in southeast Tennessee, to disconformable to in northeast Tennessee and southern Virginia, suggests that the uplift

FIG. 5-5 - Stratigraphy of the Ocoee Supergroup (east of the Greenbrier fault) and Mount Rogers Formation. Modified from Hadley and Goldsmith (1963) and Rankin (1967).

Age			
Latest Proterozoic to Early Cambrian	Chilhowee Group		
Late Proterozoic	OCOEE SUPERGROUP	Walden Creek Group	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation
		Unclassified Formation	Cades Sandstone Sandstones of Webb Mountain and Big Ridge Rich Butt Sandstone
		Snowbird Group	Metcalf Phyllite Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
Middle Proterozoic	Grenville Basement		

Age		
Latest Proterozoic to Early Cambrian	Chilhowee Group	
Late Proterozoic	MOUNT ROGERS FM.	upper member - glaciogenic strata
		middle member - interbedded latites and rhyolites
		lower member - cobble conglomerates with minor basalt and rhyolite
Middle Proterozoic	Grenville Basement	

FIG. 5-6 - Basal conglomerate of the Unicoi Formation (A), Hot Springs window, North Carolina containing clasts similar in lithology to underlying Sandsuck Formation (B).


A
B

affecting the region to the northeast (Virginia promontory) was greatly reduced or absent in the Ocoee basin of the Tennessee embayment to the southwest (Fig. 5-4) and therefore it is unlikely to represent a break-up unconformity.

In northeastern Tennessee and southern Virginia, the basal unit of the Chilhowee Group is a 400 - 500 m thick lithic and feldspathic conglomerate to pebbly sandstone sequence with interbedded quartzose lithologies termed the Unicoi Formation. In many parts of the area the lower Unicoi (unlike the Cochran to the south) contains one or two basalt flows that range in thickness from less than 1 to 10 m (King and Ferguson, 1970; Simpson and Eriksson, 1989; Misra and Walker, 1990). Geochemical analyses of samples collected at five localities from Roanoke, Virginia to Erwin, Tennessee, show the flows to be tholeiitic high-Ti basalt (44-52 wt. percent SiO_2), characterized by a relatively narrow range of compatible and incompatible elements. The Y/Nb ratios suggest they are within-plate continental tholeiites while the Zr/Y ratios of some samples are more indicative of MORB affinity. These apparent variations in tectonic affinity are consistent with previous interpretations of Unicoi strata as representing late-rift to early drift-phase sedimentation (Williams and Hiscott, 1987; Simpson and Eriksson, 1989; Misra and Walker, 1990). In this area the Unicoi Formation: 1) disconformably overlies the Sandsuck Formation of a stratigraphically thinner Walden Creek Group (Hot Springs window, North Carolina; Oriel, 1950); 2) nonconformably overlies Grenvillian basement (northeasternmost Tennessee and southwestern Virginia; King and Ferguson, 1970; Simpson and Eriksson; 1989), and 3) disconformably overlies the Upper Proterozoic Mount Rogers Formation in south-central Virginia (Rankin, 1967; Thomas, 1977; Simpson and Eriksson, 1989).

Facies Architecture and the Sediment-dispersal System

Facies analysis of rocks of the Cochran and Unicoi Formations indicate deposition occurred during a period of relative sea-level rise. Both formations can best be described as texturally and mineralogically immature pebbly sandstone and conglomerate displaying a restricted range of primary sedimentary structures and cross-stratification types. The coarse-grained basal strata give way upsection to mineralogically and texturally mature quartz sandstone possessing a more diverse suite of stratification types indicative of both unidirectional and oscillatory flow (Walker and others, 1988; Simpson and Eriksson, 1989; see Chapter 3 for more discussion).

Analysis of the various primary sedimentary features preserved in the upper portion of the Cochran-Unicoi interval indicates deposition in a variety of marine environments ranging from upper shoreface to inner shelf (Walker and others, 1988; Simpson and Eriksson, 1989; see Chapter 3 for more discussion). Because the facies architecture of the lower fluvial interval is more pertinent to the discussion of tectonic setting as elucidated by variation in sandstone composition, the lower Cochran-Unicoi interval will be discussed in greater detail .

Fluvial strata of the Cochran and Unicoi Formations. Examination of stratification preserved within the lower portion of the Cochran and Unicoi Formations allows for the recognition of three dominant facies: 1) a matrix-supported conglomerate facies (described as granule to pebble conglomerate with a matrix consisting of clay- to very coarse sand-sized material and lacking internal stratification. NOTE: this facies is restricted to the Unicoi Formation of northeastern Tennessee and southern Virginia; Simpson and Eriksson, 1989); 2) clast-supported conglomerate facies (Cudzil and Driese, 1987; Skelly, 1987; Walker and others, 1988; Simpson and Eriksson, 1989); and 3) interlaminated sandstone-mudstone facies described as horizontally laminated mudstone and sandstone with minor cross-stratification at the base (Skelly, 1987; Walker and others, 1988; Simpson and Eriksson, 1989; see Chapter 3 for more discussion). The clast-supported conglomerate facies can be further subdivided into three variants that include: 1) a massive variant described as planar- to lenticular-bedded, clast-supported conglomerate lacking internal stratification; 2) a large-scale cross-stratified variant described as large-scale planar-tabular cross-stratified clast-supported conglomerate, with individual beds commonly possessing a erosional base and rippled top (Cudzil and Driese, 1987; Walker and others, 1988; Simpson and Eriksson, 1989; see Chapter 3 for more discussion); and 3) a horizontally laminated sandstone variant described as a horizontally laminated, small-scale cross-stratified sandstone commonly interbedded with rocks of the previous conglomerate variants (Cudzil and Driese, 1987; Walker and others, 1988; Simpson and Eriksson, 1989; see Chapter 3 for more discussion).

These facies and associated variants are interpreted as representing hyperconcentrated-flow deposits (matrix-supported conglomerate facies), longitudinal bar deposits (massive variant of conglomerate facies), transverse bar deposits (large-scale cross-stratified variant of the conglomerate facies), flood-plain vertical accretion deposits (horizontally laminated sandstone variant of the conglomerate facies) of a braided stream system, and lacustrine deposition (interlaminated sandstone and mudstone facies). Collectively these facies indicate that the lower portion of the Cochran and Unicoi Formations probably represents a distal alluvial fan system which graded distally into a complex system of braided stream and ephemeral lakes associated with a coastal braid plain (Walker and other, 1988; Simpson and Eriksson, 1989). The restriction of the alluvial fan deposits of the Unicoi to northeastern Tennessee and southern Virginia is indicative of a restriction of tectonically induced relief to that area.

Examination of paleocurrent data compiled from a number of studies (Schwab, 1972; Whisonant, 1974; Cudzil and Driese, 1987; Skelly, 1987) indicates that the vast fluvial system responsible for transport and deposition of sediment preserved as lower Cochran and Unicoi strata was supplied from drainage areas located cratonward (Fig. 5-7). The gross vertical facies arrangement seen throughout the area is also indicative of progradation of these non-marine deposits from the craton toward the present day east. Because of this general pattern of southeastern directed paleoflow, and the general consistency of depositional environment along strike variation in sandstone composition reflects true changes in source rocks types distributed along the evolving rifted margin.

METHODS

In order to document variation in sandstone composition along depositional strike across the Tennessee embayment and Virginia promontory, eight stratigraphic sections were systematically sampled (n=112; Fig. 5-1). Sample localities were chosen to maximize data from complete sections overlying all three basement types (i.e., Cochran over Sandsuck, Unicoi over Sandsuck, Unicoi over crystalline basement, and Unicoi over Mt. Rogers). Samples were collected at roughly ten-meter intervals with particular attention paid to sampling beds consisting of medium to coarse sand. Thin-sections were prepared and point-counted using the Gazzi-Dickinson method (G-D method; Table 5-1). In addition a separate record of the occurrence of plutonic lithic grains (quartzo-feldspathic grains) was kept in order to accurately record the existence of such grains (for more complete discussion see Ingersoll and others, 1984). Three hundred framework

FIG. 5-7 - Paleocurrent vectors from the Cochran and Unicoi Formations. Compiled from Schwab (1972), Whisonant (1974), and Cudzil and Driese (1987) by Skelly (1987).

Basal Fluvial Paleoflow
(Cochran / Unicoi Time)

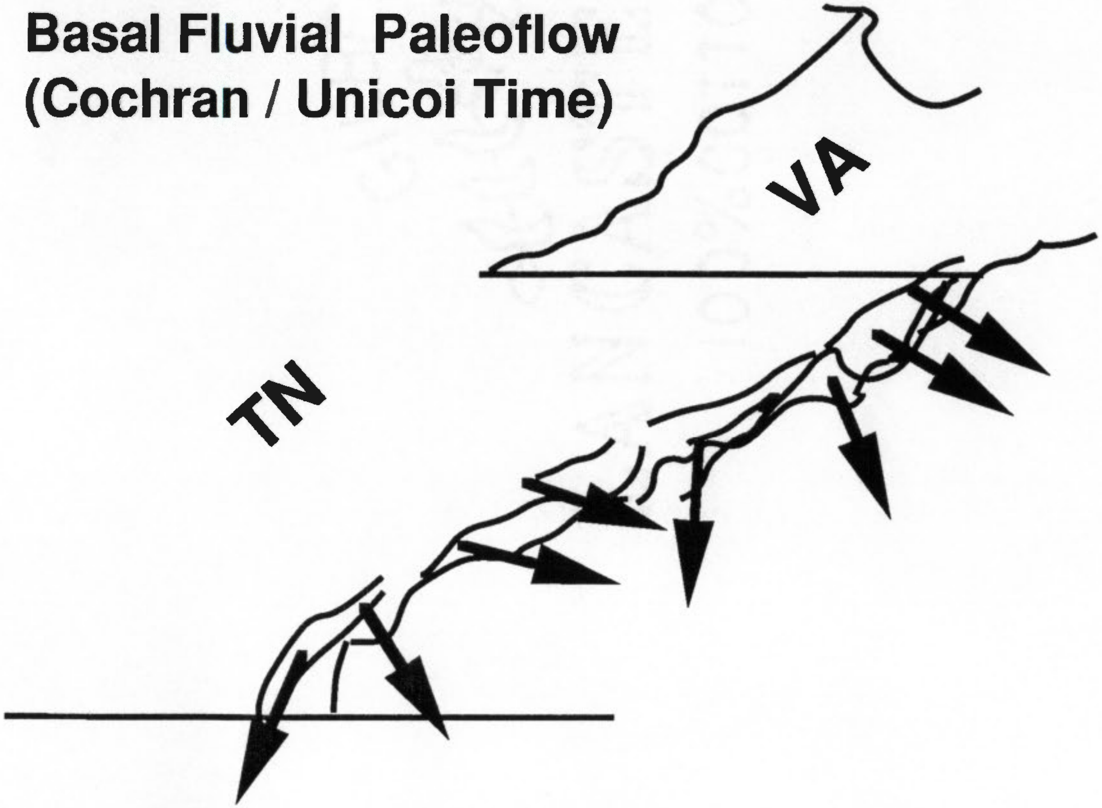


TABLE 5-1. - *Grain Parameters (after Dickinson 1970; Graham et al. 1976; Ingersoll and Suczek 1979)*

Qp = polycrystalline quartz (inc. chert)	Q = Qm + Qp
Qm = monocrystalline quartz	F = P + K
P = plagioclase feldspar	L = Lv + Lm + Ls + Lp
K= potassium feldspar	
	Framework = Q + F + L + O
Lv = volcanic-hypabyssal lithic fragments	QFL%Q = 100Q / Q + F + L
Lm = metamorphic lithic fragments	QFL%F = 100F / Q + F + L
Ls = sedimentary lithic fragments	QFL%L = 100L / Q + F + L
Lp* = plutonic lthic fragments (quartzo-feldspathic grains)	
O = other (micas, opaque grains)	WR%Qm = 100Qm / Framework
	WR%F = 100F / Framework
	WR%L = 100L / Framework

grains were counted per slide, therefore the resulting modal abundance of individual samples were accurate to +/- 5 percent whole rock (Van der plas and Tobi, 1965; Dickinson and Suczek, 1979). Because two operators were involved in point counting (Walker counted Tennessee samples, n = 61; Simpson counted Virginia samples, n = 51) special attention was made to insure agreement as to the identification of the various grain types. After mutual examination and discussion of an extensive collection of photomicrographs and thin sections, selected lithologies were point counted by both operators and the resulting counts compared, differences within the resulting modal abundances were consistently within the 5 percent error associated with the G-D method.

All data were then compiled and categorized by sample locality. Three major aspects of sandstone composition were then examined: 1) overall source rock types represented by the various framework grains recognized; 2) variation in the whole-rock abundance of mono-crystalline quartz (Qm), total feldspar (F), and labile lithic grains (L) as a function of stratigraphic position for each locality; and 3) variation in overall normalized total quartz (Q), F, and L signature from locality to locality (Table 5-1).

SANDSTONE PETROLOGY AND PROVENANCE

The use of ternary plots to graphically illustrate the relative proportions of detrital framework grains has proven to be a valuable tool in the reconstruction of the plate interactions responsible for the development of various siliciclastic depositional systems (Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Ingersoll and others, 1984; Mack, 1984). Despite the successes and advantages of ternary compositional diagrams, the indiscriminate use of compositional diagrams can lead to oversimplification of the underlying tectonic processes (Mack, 1984). To reduce the error associated with the use of compositional diagrams, it is necessary to constrain the resulting interpretations with independently derived paleogeographic and paleotectonic data. As previously shown, source area locations can be constrained by documentation of the regional sediment dispersal system and facies architecture. Likewise, the gross plate tectonic setting can be inferred from regional stratigraphic relationships. Prior to the use of ternary compositional diagrams to make inferences about variations in regional tectonic patterns, the various framework grains identified within basal Chilhowee strata (and associated source rock signatures) must be reconciled with known source terranes.

The post-depositional effects of diagenesis may also modify precursor sediment composition by the chemical alteration and elimination of certain susceptible labile grains. Previous studies have documented the role of diagenesis in altering the composition of sandstone and have provided some guidelines for the assessment of the degree of modification experienced by individual samples (e.g., McBride, 1984; Walker and others, 1978; Shanmugam, 1984; and Helmund, 1984). Pertinent to the study discussed here are a number of diagenetic processes (documented in rocks of similar composition) that include: 1) illitization of plagioclase feldspar grains; 2) production of polycrystalline quartz grains by the compaction of silt-sized quartz grains; and 3) dissolution or alteration of K-feldspars as evidenced by kaolinite ghosts, remnant clay rims, or oversized pores (McBride, 1984; Shanmugam, 1984; and Helmund, 1984).

Examination of Cochran and Unicoi samples resulted in the recognition of the following diagenetic features: 1) restricted occurrences of early sparry calcite cement, 2) in situ alteration of detrital feldspar and felsic volcanic grains to clay minerals ghosts (rarely was this advanced enough to result in questionable identification of precursor detrital grain); 3) alteration of mafic volcanic grains to chlorite, and 4) precipitation of phyllosilicate cement (restricted to samples within the Unicoi Formation). Polycrystalline grains observed possessed easily distinguished detrital grain boundaries. Furthermore the subgrains within in any one grain varied in size dramatically, therefore these polycrystalline quartz grains are interpreted as representing the nature of the source rock and not the suturing of detrital silt. Based on the above observations and criteria put forth in previous studies, the variation in sandstone composition documented within samples of Cochran and Unicoi Formations discussed below accurately reflects variations in the composition of the precursor sediment.

Framework Grain Provenance

Inspection of thin-sections prior to actual point-counting led to the recognition of several detrital framework grain types including monocrystalline quartz grains (some with abraded overgrowths), polycrystalline quartz grains (in which subgrains possess sutured boundaries), monocrystalline plagioclase feldspar and potassium feldspar grains, lithic mafic volcanic grains, lithic felsic volcanic grains, lithic low-rank metamorphic grains (usually slate), lithic sedimentary grains (usually detrital siltstone grains), quartzo-feldspathic grains (lithic granitic-gneissic grains containing some combination of intergrown quartz, plagioclase feldspar, potassium feldspar and/or muscovite), detrital mica grains, detrital amphibole grains, and minor opaque, detrital heavy mineral grains (Table 5-2, Fig. 5-8). Carbonate rock fragments and recognizable sedimentary chert grains were not observed.

Polycrystalline quartz (with 2-3 sutured subgrains) and quartzo-feldspathic grains are indicative of granitic-gneissic source terranes (Basu and others, 1975; Dickinson and Suczek, 1979). Lithic mafic and felsic volcanic grains are obviously indicative of volcanic source rocks. These sources may be intra- or extrabasinal in character (Zuffa, 1980). Monocrystalline quartz grains with abraded overgrowths are indicative of sedimentary source terranes. Monocrystalline potassium and plagioclase feldspar grains, monocrystalline quartz grains (lacking abraded overgrowths), detrital mica and amphibole grains, and heavy minerals may be indicative of plutonic, gneissic, volcanic, or sedimentary source terranes or any combination these terranes (Dickinson and Suczek, 1979). Low-rank metamorphic grains, such as detrital slate grains, and polycrystalline quartz (with 7 or more sutured subgrains) are indicative of source terranes composed of low-grade metamorphosed sedimentary rock (Basu and others, 1975; Table 5-2).

While it is impossible to say with 100 percent certainty that a detrital grain was derived from any particular stratigraphic unit, the various stratigraphic units that underlie the basal Chilhowee strata can be sited as obvious candidates as source terranes for the various framework grains described above (Table 5-2). The Mount Rogers Formation can be described as a volcanic and siliciclastic sequence containing both mafic and felsic volcanic units as well as fine grained siliciclastic (siltstone) sequences. The Grenvillian basement exposed throughout the area consists of a variety of felsic plutonic sequences as well as high grade gneissic rock (King and Ferguson, 1970; Bryant and Reed, 1970; Bartholomew and Lewis, 1984). The Ocoee Supergroup contains a wide variety of siliciclastic marine and non-marine units as well as minor carbonate sequences. Although the nature of the contact between the uppermost portion of the Ocoee Supergroup (Sandsuck Formation of the Walden Creek Group) and Unicoi Formation is at least in part disconformable, the occurrence of clasts identical to Sandsuck lithologies in the basal conglomerate of the Chilhowee Group *do not* indicate significant uplift or that the stratigraphically lower portion of the Ocoee acted as source terranes for Chilhowee detrital

FIG. 5-8 - Photomicrographs of the various detrital grains observed in the Cochran and Unicoi Formations. Field of view is 1.5 mm in long dimension of each photo. A = detrital quartzo-feldspathic rock fragment containing plagioclase feldspar and quartz; B = detrital plagioclase feldspar grain exhibiting tartan twinning; C = detrital polycrystalline quartz grain, note increase in grain size towards the base of photo and the foliated nature of grain; D = felsic volcanic rock fragment; E = altered detrital potassium feldspar grain at extinction, note alteration intense along fractures yet rest of grain is identifiable; F = same altered detrital potassium feldspar grain not at extinction.

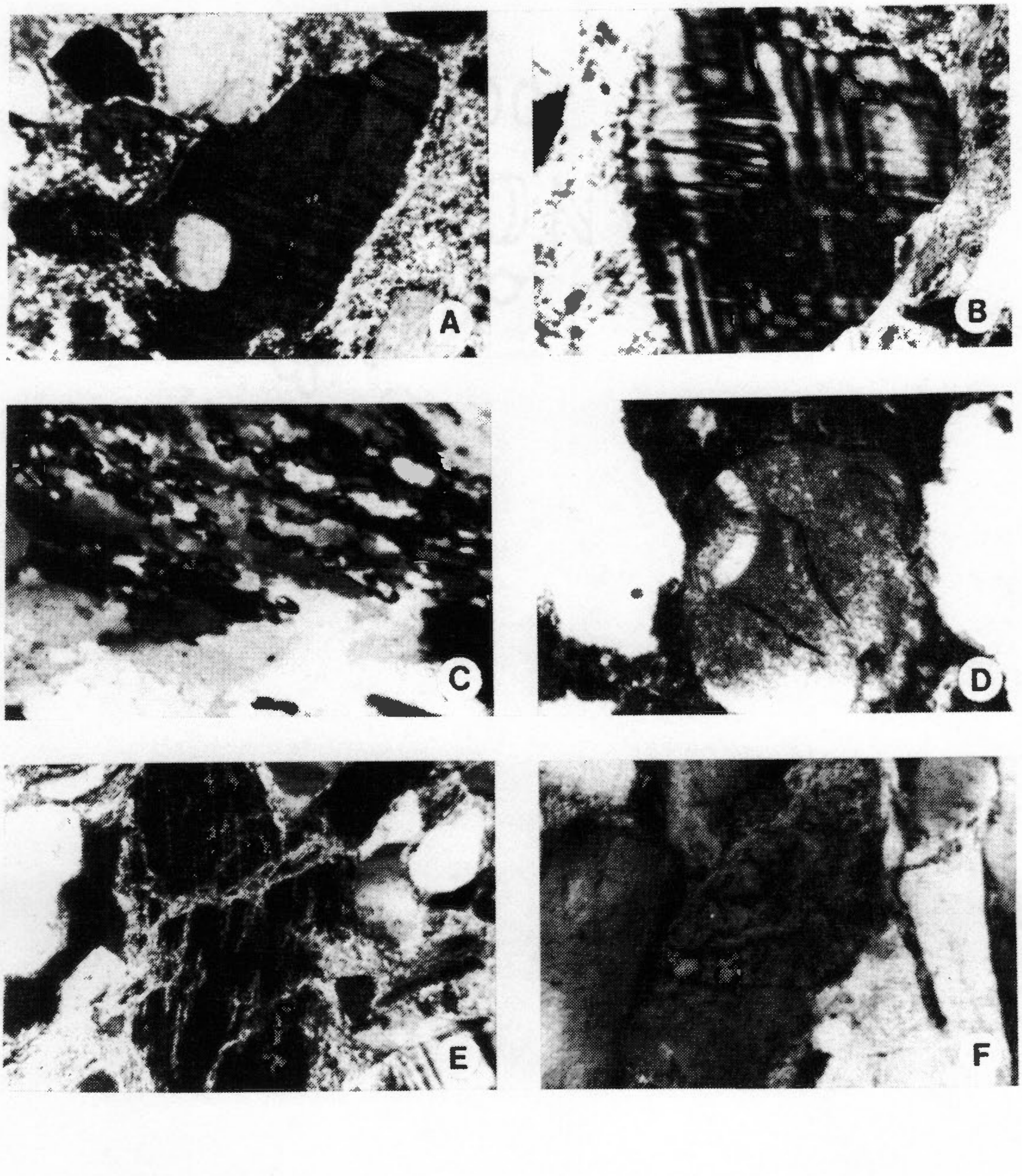

A
B
C
D
E
F

TABLE 5-2. - *Grain types recognized and their proposed provenance*

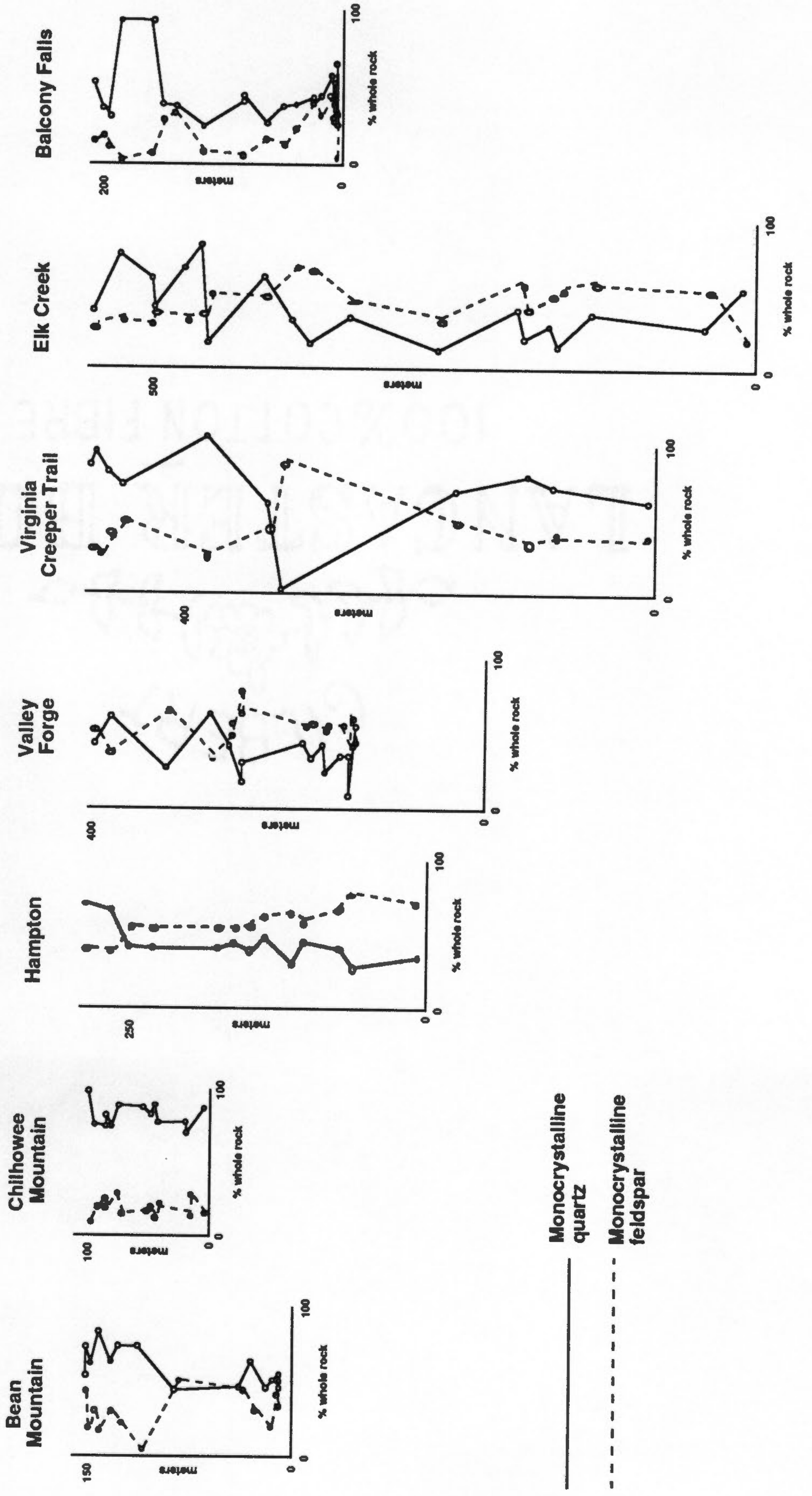
Qm1	= monocrystalline quartz grains (lacking abraded overgrowths)	- sedimentary, low-grade metamorphic, granitic-gneissic, or volcanic source rocks
Qm2	= monocrystalline quartz grains (possessing abraded overgrowths)	- sedimentary source rocks
Qp1	= polycrystalline quartz grains (2-3 subgrains with sutured boundaries)	- high-grade metamorphic or igneous source rocks
Qp2	= polycrystalline quartz grains (>3 subgrains with sutured boundaries)	- low-grade metamorphic source rock
P	= monocrystalline plagioclase feldspar grains	- sedimentary, volcanic, or granitic-gneissic source rocks
K	= monocrystalline potassium feldspar grains	- sedimentary, volcanic, or granitic-gneissic source rocks
LvM	= lithic mafic volcanic grains	- mafic volcanic source rocks
LvF	= lithic felsic volcanic grains	- felsic volcanic source rocks
Ls	= lithic sedimentary grains (siltstone)	- fine-grained sedimentary source rocks
Lm	= lithic low-grade metamorphic grains (slate)	- low-grade regionally metamorphic source rocks
QFF	= quartzo-feldspathic grains	- granitic-gneissic source rocks
M	= detrital mica grains	- granitic-gneissic source rocks
A	= detrital amphibole grains	- mafic plutonic or high grade metamorphic source rocks
O	= unidentified opaque heavy mineral grains	

grains. Less than 20 meters separates the Sandsuck lithologies from the basal conglomerate of the Unicoi Formation within the Hot Springs window, therefore only minor changes in base-level (either tectonically or eustatically induced) on the order of 20 meters may be invoked to explain the existence of this erosional disconformity. The only grain types that cannot be accounted for by known source terranes in the area are the low-rank metamorphic and polycrystalline (>3 subgrains) quartz grains. The authors suggest two possibilities: 1) they may represent sediment derived from now unexposed portions of a low-grade metamorphic belt associated the Grenville orogeny, or 2) they may represent sediment derived from low-grade metamorphic terranes yet unidentified in the southern Appalachians.

Percent Qm, F, and L as a Function of Stratigraphic Position

Examination of whole rock abundances of monocrystalline quartz, feldspar, and lithic grains results in the recognition of changes in their relative importance as a function of stratigraphic position (Fig. 5-9). The overall reduction in the whole-rock abundance of feldspar and lithic grains upsection can be attributed to a variety of factors which are generally associated with either changes in source terrane or depositional process through time. Diagenesis may also result in differences between sandstone composition and the original sediment composition. As previously discussed, diagenetic effects were accounted for and therefore the following discussion is based on the conclusion that the composition of the sandstones reflects the true composition of the precursor sediment. Because the apparent decrease upsection in the abundance of feldspar and lithic grains is coincident with a documented change from a fluvial depositional system to a marine depositional system (Cudzil and Driese, 1987, Walker and others, 1988; Simpson and Eriksson, 1989; see Chapter 2 for more discussion), changes in depositional processes must be considered as a viable mechanism for affecting the observed change in sandstone composition. Sediment composition may be effected by several means including: 1) reduction of labile grain fraction by mechanical abrasion associated with increased transport (Bradley, 1970; Davies and Ethridge, 1975; Mack, 1978; Houseknecht, 1980; Suttner and others, 1981; among others); 2) reduction of the detrital feldspar and labile grain fraction by increased reworking associated with higher energy environments (e.g., shallow marine environments; Bradley, 1970; Davies and Ethridge, 1975; Mack, 1978;

FIG. 5-9 - Variation in the whole rock abundances of monocrystalline quartz (Qm) and monocrystalline feldspar (F) in various sections of the Cochran and Unicoi Formations, eastern Tennessee and southern Virginia.


Balcony Falls
Elk Creek
Virginia Creeper Trail
Valley Forge
Hampton
Chilhowee Mountain
Bean Mountain
meters
% whole rock
Monocrystalline quartz
Monocrystalline feldspar

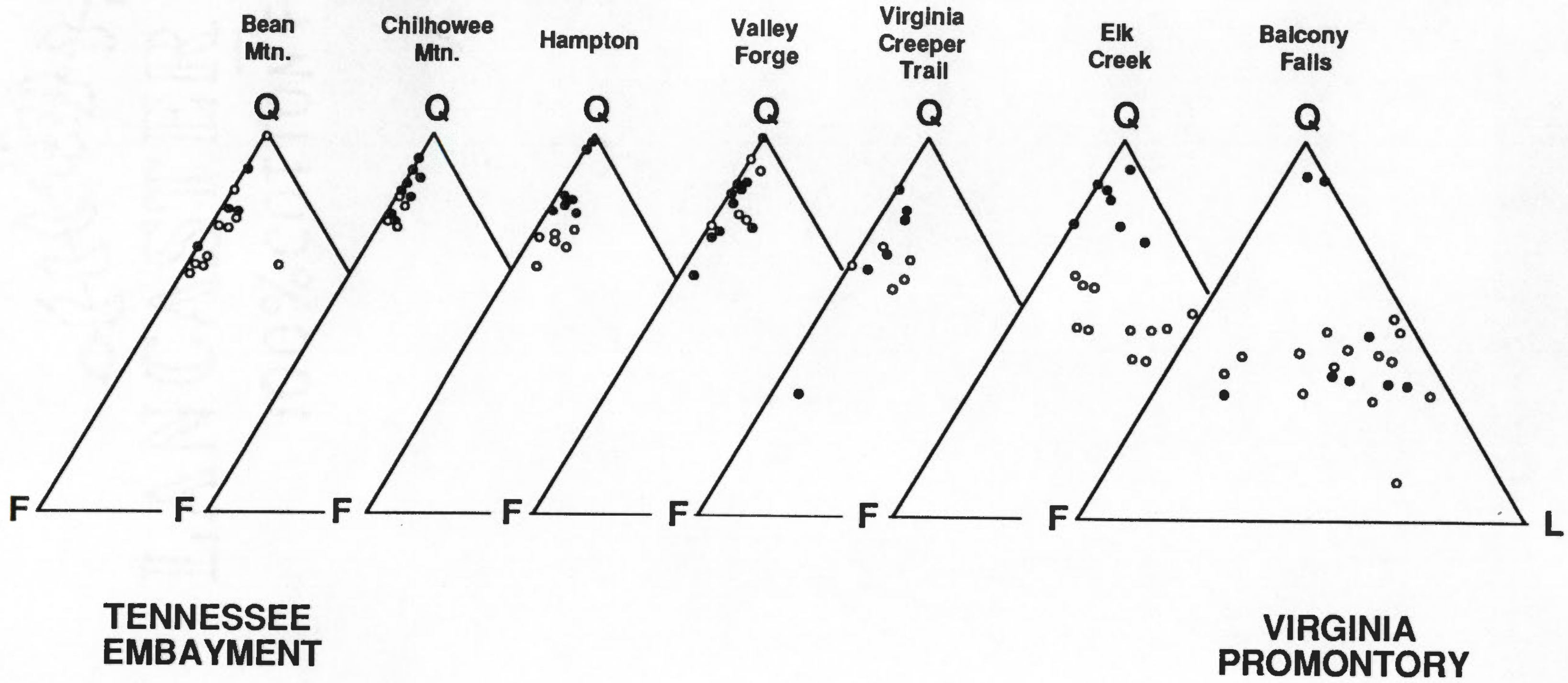
Houseknecht, 1980; among others); 3) whole-rock abundance of detrital feldspar and labile grains may be reduced by dilution as mono-crystalline quartz grains are introduced from new source terranes (e.g., introduction of more mature sand by longshore currents), or 4) some combination of all three mechanisms. Because previous studies have documented the viability of labile grain reduction by sediment reworking (Suttner and others, 1981; Suttner and Basu, 1985) and have identified within the upper portion of the Cochran and Unicoi Formation facies interpretable as representing littoral deposition and alongshore bar migration (Cudzil and Driese, 1987; Walker and others, 1988; Simpson and Eriksson, 1989) all three mechanisms must be accepted as operating.

Relative Abundance of Q, F, and L by Locality

The effects of differences in the amount of transport experienced by grains of differing units can be reduced by comparing rocks of similar fluvial depositional settings. Suttner and others (1981) convincingly demonstrated that sediment composition is not greatly affected by mechanical abrasion in circumstances were the sediment has experienced less than 75 km of transport. As all of the fluvial facies sampled represent distal alluvial fan to coastal braid plain environments it is assumed that any tectonic activity within 75 km of the site of deposition has been recorded as a recognizable change in sandstone composition. As the transition from fluvial to marine deposition can be documented in all sections sampled, the affects can be accounted for by comparing trends in sandstone composition below the first occurrence of strata interpreted as representing marine deposition. Consequently, the comparison of the relative abundance of Q, F, and L from locality to locality discussed here will be based on trends observable in *both* the entire sample population and that subset of the population representing samples taken exclusively from below the documented fluvial-to-marine transition (Fig. 5-10).

The relative abundance of total quartz grains (Q), total feldspar grains (F), and labile lithic grains (L) changes dramatically along depositional strike (Fig. 5-10). Because this trend is observable both within the entire population of samples and those taken from below the fluvial-to-marine transition it is interpreted here as representing fundamental changes in the nature of the source rocks providing sediment to the respective segments of the depositional system. Suites of sandstone samples taken from the Cochran Formation of the Tennessee reentrant are systematically richer in quartz and feldspar and lower in

FIG. 5-10 - QFL ternary plots of Cochran and Unicoi Formation sandstone samples. Open circles represent samples taken exclusively from fluvial strata stratigraphically below the first occurrence of marine diagnostic facies.


Bean Mtn.
Chilhowee Mtn.
Hampton
Valley Forge
Virginia Creeper Trail
Elk Creek
Balcony Falls
Q
F
L
TENNESSEE EMBAYMENT
VIRGINIA PROMONTORY

lithic grains than their counterparts taken from the Unicoi Formation to the northeast. This transition from more mature sediment to the southwest to more lithic and feldspar rich to the northeast persists even in samples taken exclusively from the Unicoi Formation (Fig. 5-10). This variation in composition along depositional strike is interpreted as representing a change from dominantly sedimentary and granitic-gneiss source terranes of moderate relief adjacent to the Tennessee reentrant to volcanic and granitic-gneissic source terranes of greater relief to the northeast in the area of the Virginia promontory.

TECTONIC MODEL

When viewed collectively the increase in the granitic-gneissic and volcanic source rocks signature on sandstone composition from the southwest (Tennessee embayment) to the northeast (Virginia promontory), the restriction of strata attributed to alluvial-fan deposition and rift-affinity mafic volcanic flows to areas adjacent to or on the Virginia promontory, and the apparent change in the nature of the basal Chilhowee contact from conformable in the southwest (Tennessee embayment) to disconformable or nonconformable to the northeast (Virginia promontory) suggest differences in the tectonic histories of the two areas. Evidence sited here is interpreted as indicating that while rift-related extension was effecting sedimentation patterns in the areas on and adjacent to the Virginia promontory, areas to the southwest in the Tennessee embayment were experiencing a period of relative tectonic quiescence. This spatial restriction of active Early Cambrian tectonism has implications for the interpretation of the evolution of this portion of the Iapetos margin, when viewed in conjunction with the underlying Upper Proterozoic stratigraphy.

The temporal relationship between rifting represented by the lower portion of the Ocoee Supergroup and Mount Rogers Formation, while undoubtedly spatially separate, is unclear. Because both sequences are overlain by the Chilhowee Group, they undoubtedly represent Late Proterozoic tectonism. As both stratigraphic sequences appear to record a transition from active faulting and volcanism (lower volcanic and conglomeratic deposits) to periods when tectonic effects appear to have been reduced in importance (glaciogenic portion of Mount Rogers Formation and the incipient carbonate shelf strata of the Walden Creek Group of the uppermost Ocoee Supergroup), these sequences are considered here to represent an earlier Late Proterozoic stage of regional extension, temporally separate from that recorded by the basal strata of the Chilhowee Group. These stratigraphic relationships in conjunction with the detailed tectonic history described for the basal Chilhowee Group strongly suggests that the morphology of the early Paleozoic Laurentian margin can be attributed to at least two major extensional events. While the early stage of extension (Synrift Stage I) affected areas within both the Tennessee embayment and Virginia promontory, extension documented by the Cochran and Unicoi interval appears to be restricted to that area adjacent to the Virginia promontory and therefore is considered a temporally and spatially distinct extensional event (Synrift Stage II).

CONCLUSIONS

A number of stratigraphic, sedimentologic, and petrologic lines of evidence suggest that the regional extension responsible for the ultimate breakup of the Late Proterozoic supercontinent occurred in spatially and temporally distinct stages, the last of which is recorded by the sediments of the Cochran and Unicoi Formations of the basal Chilhowee Group. This evidence can be summarized as follows:

1) The distribution of Upper Proterozoic volcanic and siliciclastic strata define a sequence of off-set rift basins (Ocoee Supergroup and Mount Rogers Formation) that collectively formed a northeast trending orthogonal continental margin (Tennessee embayment and Virginia promontory);

2) The stratigraphic relationship within these units indicates that during deposition both basins experienced a transition from active extension and volcanism to periods of relative tectonic quiescence (represented by change from siliciclastic to carbonate deposition in the Ocoee Supergroup and the cessation of volcanism and conglomerate deposition to glaciolacustrine or glaciomarine deposition in the Mount Rogers Formation);

3) Lithic and feldspathic strata and intercalated mafic volcanic flows of the Unicoi Formation record a regional restricted extensional event during latest Proterozoic and Early Cambrian time;

4) Comparison of the lithologic and petrologic signature of the Unicoi Formation with its southwestern equivalent, the Cochran Formation, indicates that this tectonism affected sedimentation patterns in northeast Tennessee, southern Virginia, and the

adjacent portions of North Carolina, while the area within the Tennessee embayment experienced a period of relative tectonic quiescence.

By examining these regional patterns it is proposed here that two temporally and spatially distinct stages of rifting can be delineated: Synrift Stage I - which affect the entire southern Appalachian region during the Late Proterozoic; and Synrift Stage II - which affected the areas adjacent to the Virginia promontory only during latest Proterozoic and earliest Cambrian time.

CHAPTER 6

TECTONO-STRATIGRAPHIC EVOLUTION OF THE LAURENTIAN - IAPETOS CONTINENTAL MARGIN, AS RECORDED BY THE CHILHOWEE GROUP AND RELATED STRATA OF THE SOUTHERN APPALACHIANS

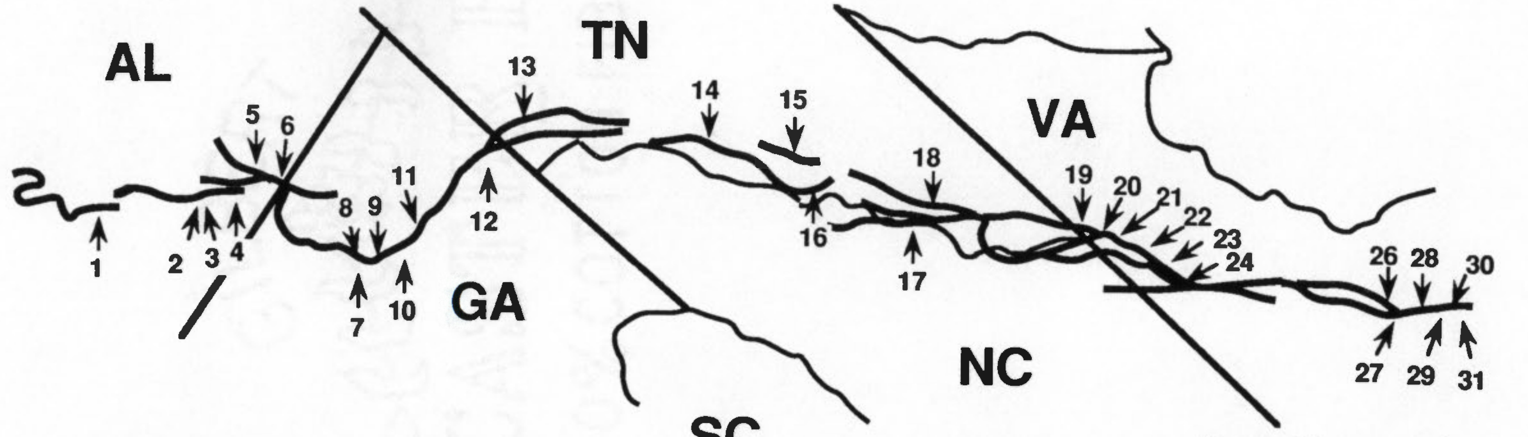
INTRODUCTION

Since Sloss's recognition of the Sauk Sequence (Sloss, 1963), much attention has been focused on the geology of the ancient North American continental margins, and the stratigraphic sequences which record their evolution. This work represents an attempt to more fully understand the paleodynamic evolution of the Laurentian - Iapetos margin (as exposed in the southern Appalachians), in view of recent advances made in our understanding of modern rift and passive-margin development, as well as the sedimentary processes inherent to each.

As with all major ocean basins, the initial Iapetos formation was marked by a major rifting event which occurred between 690 and 570 Ma (Odom and Fullgar, 1984). During this event, major attenuation of the 1.1 Ga Grenvillian basement occurred, resulting in the formation of discontinuous rift basins and associated volcanic centers, isolated basement blocks, and an irregular continental margin morphology (Hatcher, 1972, 1987, 1989; Rankin, 1975, 1976; Thomas, 1977, 1983). Continued extension culminated with the initiation of oceanic crust formation, marking the inception of the Iapetos ocean, and the formation of twin, opposing, passive continental margins and associated micro-continents. The irregular continental morphology is generally accepted as being a primary factor in the distribution of the post-rift sedimentary sequence, as well as subsequent Paleozoic orogenic deformation (Thomas, 1977, 1983).

The sedimentologic record of the of the stabilization of the North American passive-margin during the development of the Iapetos ocean, is contained in the Chilhowee Group (uppermost Proterozoic to Lower Cambrian; see Chapters 2 and 3 for more discussion of age constraints and sedimentology, respectively). This group possesses a complex stratigraphic nomenclature, and is exposed in discontinuous strike-belts from Alabama to Newfoundland. In the southern Appalachian region, the Chilhowee Group is composed of dominantly terrigenous sequences, deposited in a wide variety of continental and continental shelf environments, and with few but significant exceptions is confined to the westernmost Blue Ridge (Figs. 6-1 and 6-2). East of this tectono-stratigraphic boundary the Chilhowee Group and possible equivalent units are typically exposed in structural windows within overlying Eastern Blue Ridge or Inner Piedmont strata (e.g., Table Rock Thrust Sheet of Grandfather Mountain; Bryant and Reed, 1960, 1970) and are associated with internal basement massifs (e.g., Sauratown Mountains of North Carolina and Pine Mountain Belt of Georgia and Alabama; Fig. 6-3; Hatcher, 1987; see Chapter 4 for more discussion). Basal Chilhowee formations were probably deposited on attenuated continental crust along a thermally subsiding continental margin (Cochran Formation of the Tennessee embayment) or in response to active crustal extension (Unicoi Formation of the Virginia promontory); in contrast, upper units (e.g., Erwin and equivalent formations) were deposited on a stabilized but slowly subsiding continental margin (Fichter and Diecchio, 1986). Paleocurrent analyses indicate derivation from westward, principally cratonic sources and a transition from a sedimentation pattern dominated by point sources associated with topographic irregularities possibly inherited from rifting (Cochran and Unicoi Formations), to a line-source pattern characteristic of more mature passive margin sedimentation (Erwin and equivalent formations; Fig. 6-4; Schwab, 1970, 1971, 1972; Whisonant, 1974; Skelly, 1987; see Chapters 3 and 5 for more discussion). Previous stratigraphic and petrologic studies throughout the Chilhowee of the western Blue Ridge (Schwab, 1970, 1971, 1972; Whisonant, 1974), as well as sedimentologic (facies analysis) studies conducted in Alabama, Georgia (Mack, 1980), Virginia (Simpson and Eriksson, 1989, 1990), and eastern Tennessee (Cudzil, 1985; Skelly, 1987; Cudzil and Driese, 1987; see Chapter 3 for more discussion) have led to some tentative interpretations of provenance and depositional environments and local margin evolution. In most of these interpretations, basal Chilhowee units are interpreted as fluvial or coastal alluvial in nature, whereas upper units are interpreted as representing shallow-marine deposition during fluctuating sea-level (Mack, 1980; Cudzil and Driese, 1987; Simpson and Eriksson, 1990; see Chapter 3 for more discussion).

FIG. 6-1. - Location of Chilhowee Group exposures within the southern Appalachians (Compiled from Mack, 1980; Cudzil, 1985; Cudzil and Driese, 1987; Skelly, 1987; Simpson and Eriksson, 1989, 1990).



Alabama (Mack, 1980)

1 - Sleeping Giants Ridge near Renfrow, Alabama
2 - Choccolocco Mountain near Piedmont, Alabama
3 - Choccolocco Mountain near Piedmont, Alabama
4 - Wilson Ridge near Piedmont, Alabama
5 - Weisner Mountain, Weisner Mountain Quadrangle, Alabama
6- Indian Mountain, Indian Mountain Quadrangle, Alabama

Georgia (Mack, 1980)

7 - Emerson, Georgia
8 - Hurricane Hollow, Allatoona Quadrangle, Georgia
9 - Cartersville Landfills, Cartersville, Georgia
10 - Dobbins Mountain, Cartersville Quadrangle, Georgia
11 - Sugar Hill Pond, NE White Quadrangle, Georgia
12 - Campground Mountain, near Eton, Georgia

Tennessee (This Study)

13 - Bean Mountain, Tennesse (Skelly, 1987)
14 - Chilhowee Mountain, Tennessee
15 - English Mountain, Tennessee
16 - I-40 south of Newport, Tennessee
17 - Valley Forge, Tennessee (Cudzil, 1985)
18 - Hampton, Tennessee

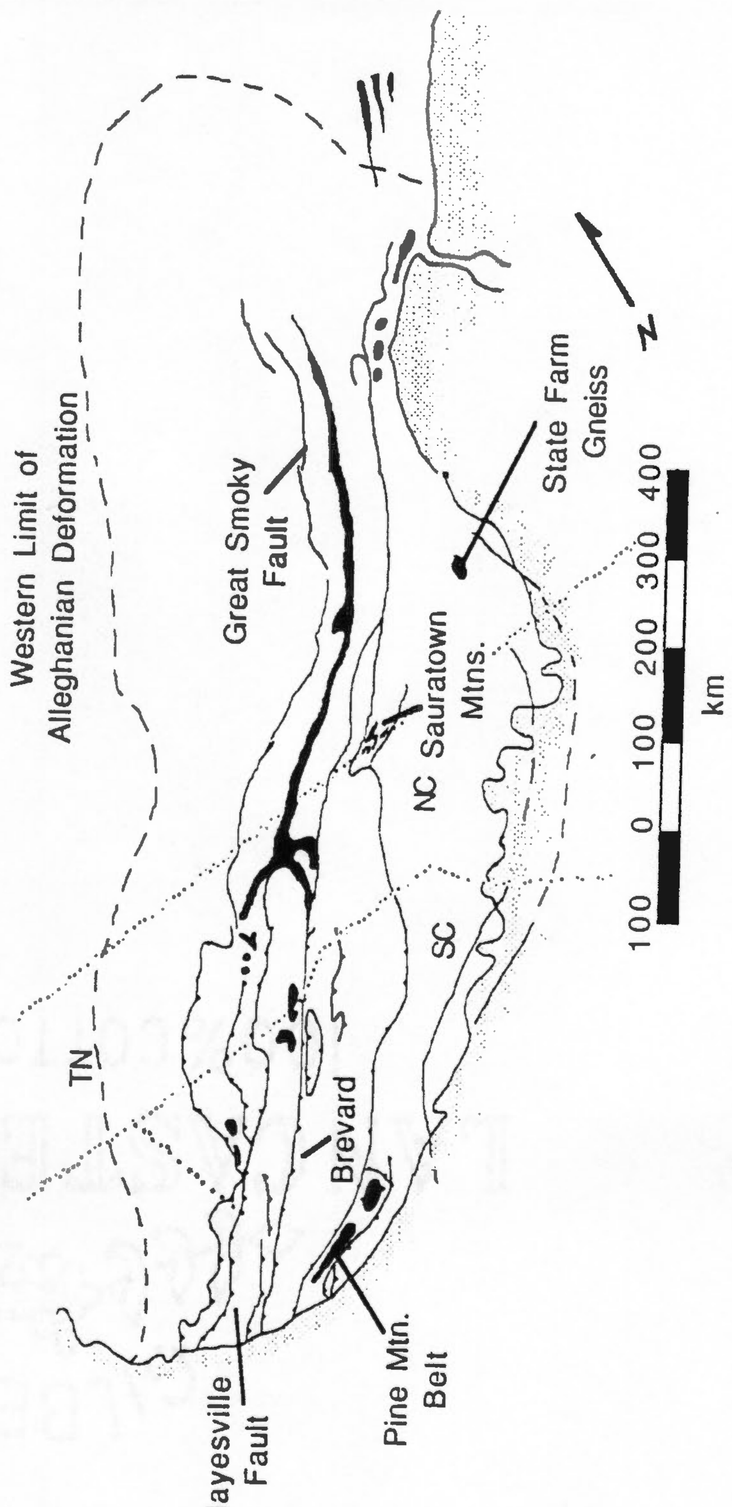
Virginia (Simpson and Eriksson, 1989, 1990)

19 - Damascus, Virginia
20 - Virginia Creeper Trail near Laurel Creek, Virginia
21 - Short Mountain, Marion Quadrangle, Virginia
22 - Elk Creek, Speedwell Quadrangle, Virginia
23 - Poplar Camp, Sylvatus Quadrangle, Virginia
24 - Poplar Camp, Fosters Falls Quadrangle, Virginia
25 - Buchanan, Virginia
26 - Arcadia, Virginia
27 - Natural Bridge Quarry, Snowden Quadrangle, Virginia
28 - Balcony Falls and Snowden, Snowden Quadrangle, Virginia
29 - Buena Vista, Buena Vista Quadrangle, Virginia
30 - Versusias, Virginia

FIG. 6-2. - Chilhowee Group stratigraphy, southern Appalachians. (Modified from Mack, 1980; Cudzil and Driese, 1987).

AGE	North Georgia and Alabama	Southeastern Tennessee	Hot Springs window, North Carolina	Northeastern Tennessee	Southwestern Virginia	Northwestern Virginia
EARLY CAMBRIAN	Shady Dolomite	Shady Dolomite	Shady Dolomite	Shady Dolomite	Shady Dolomite	Tomstown Dolomite
	CHILHOWEE GROUP: Weisner Formation	Helenmode Formation	Erwin Formation: Helenmode Member	Erwin Formation: Helenmode Member	Erwin Formation	Antietam Quartzite
		Hesse Quartzite	Hesse Quartzite Member	Hesse Quartzite Member		
	Wilson Ridge Formation	Murray Shale	Murray Shale Member	Murray Shale Member		
		Nebo Quartzite	Nebo Quartzite Member	Nebo Quartzite Member		
	Nichols Shale	Nichols Shale	Hampton Shale	Hampton Shale	Hampton Shale	Harpers Formation
	Cochran Formation	Cochran Formation	Unicoi Formation	Unicoi Formation	Unicoi Formation	Weaverton Quartzite
?						Loudon Formation
PROTEROZOIC	base of section always faulted out	Ocoee Supergroup: Sandsuck Formation	Ocoee Supergroup: Sandsuck Formation	Mount Rogers Volcanic Group or Grenville basement	Mount Rogers Volcanic Group	Catoctin Greenstone or Swift Run Fm. or injection complexes

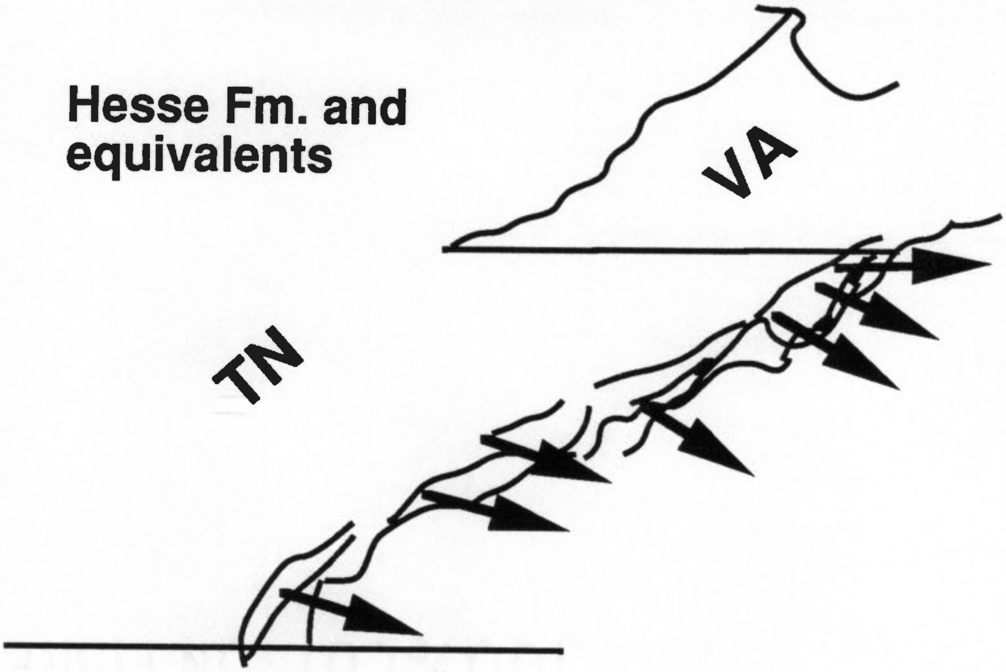
FIG. 6-3. - Location of Southern Appalachian basement massifs and their possible Chilhowee Group cover sequences (From Hatcher, 1984).



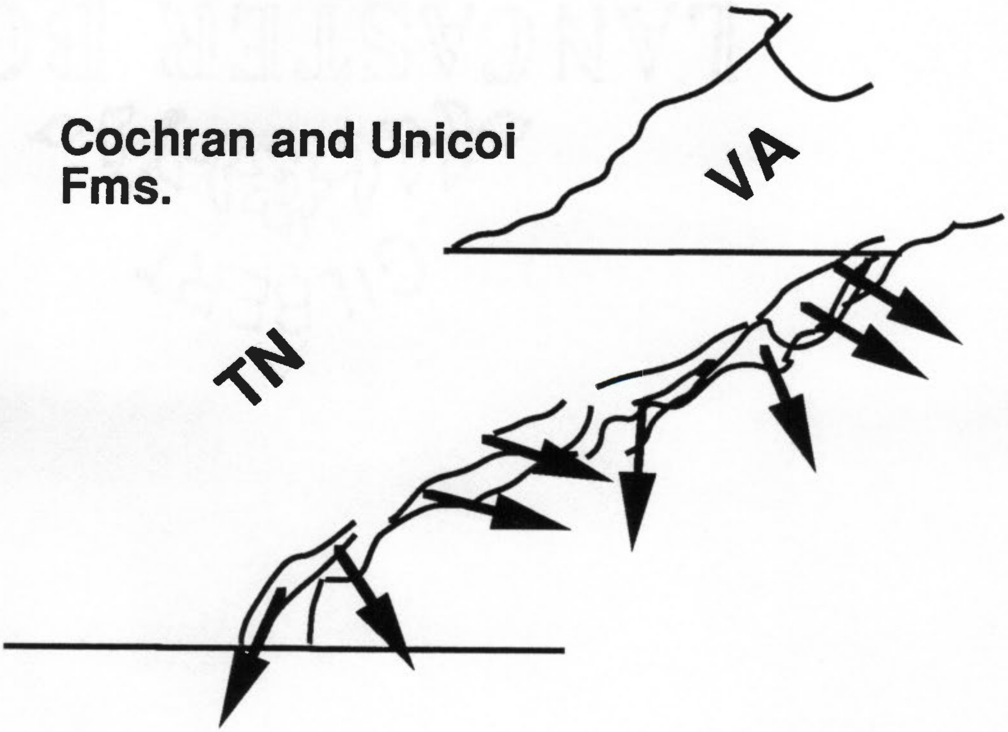
Western Limit of
Alleghanian Deformation
Great Smoky
Fault
State Farm
Gneiss
NC Sauratown
Mtns.
SC
TN
Brevard
Pine Mtn.
Belt
Hayesville
Fault
N
100 0 100 200 300 400
km

FIG. 6-4. - Regional paleocurrent trends through time (from Skelly, 1987; compiled from Schwab, 1972; Whisonant; 1974)

Hesse Fm. and equivalents



Cochran and Unicoi Fms.



PRE-CHILHOWEE GROUP STRATA OF THE WESTERN BLUE RIDGE

Pre-Chilhowee Group strata of the western Blue Ridge, include a series of regionally discontinuous units which possess complex and poorly understood stratigraphic relationships. The Chilhowee Group disconformably or nonconformably overlies three major Proterozoic units including the Ocoee Supergroup (southeastern and east-central Tennessee and west central North Carolina), Grenvillian basement (northeastern Tennessee and southern Virginia), and the Mt. Rogers Formation (southern Virginia; Table 6-1; Fig. 6-5).

Ocoee Supergroup

The Ocoee Supergroup (upper Proterozoic) is an excellent example of the evolution of understanding of Western Blue Ridge stratigraphy. Since its original definition as the Ocoee Slate and Conglomerate by Safford (1856, 1869) , the Ocoee has been variously ranked as a formation, as a group (Keith, 1895; 1896), as a series (Stose and Stose, 1944; 1949) and finally as a supergroup by officers of the U.S.G.S. The Ocoee Supergroup is a large body of dominantly terrigenous clastic sedimentary rocks, estimated to exceed 12 km in thickness at some localities (Rast and Kohles, 1986). Although many workers (e.g., (Rast and Kohles, 1986) generally regard the Ocoee being devoid of both fossils and volcanics, recent studies have demonstrated that restricted occurrences of microfossils (acritarchs) and metamorphosed mafic bodies do occur and provide some information on the history of this basin-fill sequence (Knoll and Keller, 1979; Misra and Lawson, in press; Fig. 6-6; Table 6-1).

A majority of the siliciclastic sediment preserved within the Ocoee Supergroup (especially the Great Smoky Group) was derived from Late Proterozoic Laurentian craton to the northeast (Thomas, 1977). The lowermost portion, however, (the Snowbird Group) was derived from continental blocks exposed to the east and southeast (Hadley and Goldsmith, 1963; Thomas, 1977; Rast and Kohles, 1986). Thomas (1977) proposed that this source terrane is represented by present-day exposures of Grenvillian granitic-gneissic basement of the eastern Great Smoky Mountains.

Amphibolites interpreted as metamorphosed mafic volcanic flows have been sampled within the lower portion of the Ocoee Supergroup near Ducktown, Tennessee. Geochemical analyses of these bodies have indicated that they possess relict trace element

TABLE 6-1. - *Summary of Upper Proterozoic and Lower Paleozoic Stratigraghy of the Blue Ridge of Virginia, North Carolina, and Tennessee (Modified from Wehr and Glover, 1985)*

WESTERN BLUE RIDGE

Unit	Area	Description	Interpretation	Source
		uppermost Proterozoic to Lower Cambrian rocks		
Chilhowee Group	Alabama to Newfoundland	Regionally continuous siliciclastic sequence 380-2280 m thick characterized by overall increase in maturity upward.	Nonmarine to marine, overall transgressive deposition on a subsiding and stabilizing shelf. Vertical succession represents transition from braided stream through marginal marine to storm dominated shelf.	Brown, 1970; Schwab, 1972; Whisonant, 1974; Cudzil and Driese, 1987; Skelly, 1987; Walker, and others, 1988
		Upper Proterozoic Rocks (690-570 Ma) (no relative order implied)		
Catoctin Fm.	Southern Pennsylvania to central Virginia	Bimodal volcanic sequence up to 670 m thick, dominated by basalt; rhyolite abundant in southern Pennsylvania; basalt flows interbedded with sandstone, conglomerate, and slate	Extensional volcanism and sedimentation in subaerial to shallow-water environments	Reed, 1955; 1964; 1969; Bartholomew, 1971; Blackburn and Brown, 1976; Gathright, 1976; Rankin, 1976; Conley, 1978
Swift Run Fm.	Northern and central Virginia	Lenticular unit at base of Catoctin Fm. up to 450 m thick; feldspathic and lithic sandstone, quartz arenite, slate, conglomerate; incalated with basalt flows and tuffs	Alluvial ("valley-fill") sedimentation and sporadic volcanism prior to Catoctin extrusion	Bloomer and Bloomer, 1947; Reed, 1955; Nelson, 1962; Bartholomew, 1971; Gathright, 1976; Conley, 1978
Ocoee Supergroup	Southwestern Virginia	Up to 3 km of interbedded volcanic and siliciclastic rock containing up to 50% rhyolite, including tillite	Extensional volcanism and glaciogenic sedimentation alluvial to deep-water environments	Rankin, 1970; 1975; Blondeau and Lowe, 1972; Schwab, 1976
Mount Rogers Fm.	Eastern Tennessee and west-central North Carolina	Up to 16 km of interbedded conglomerate, sandstone, slate, phyllite, and carbonate which thins dramatically to the west	Shallow-marine changing to deep-water deposition in complex extensional system	Hadley and Goldsmith, 1963; Hadley, 1970; De Windt, 1975; Rast and Kohles, 1986
Grandfather Mountain Fm.	Northwestern North Carolina	3 to 9 km of feldspathic arenite, conglomerate, and silstone; minor basalt and rhyolite	Alluvial sedimentation and volcanism in graben setting, minor ice-rafting	Bryan and Reed, 1970; Rankin, 1970; Schwab, 1977; 1981

EASTERN BLUE RIDGE

Unit	Area	Description	Interpretation	Source
		Upper Proterozoic to Lower Cambrian Rocks (no relative time stratigraphic order implied)		
Chilhowee Group	Southern Pennsylvania to Central North Carolina	Quartzite, micaceous and feldspathic quartzite, and phyllite	Alluvial to shallow marine	Whitaker, 1955; Nickleson, 1956; Schwab, 1972; Espenshade and Clarke, 1976; Walker, in progress
Evington Group	Central Virginia	Mostly metasedimentary sequence dominated by phyllite with thin sandstone interbeds (Candler Fm.); also contains thin units of marble, quartzite and greenstone	Deep marine (Brown, 1970; Evans, 1984) or shallow marine (Conley, 1978); Candler Fm. may be basinal euivalent to Chilhowee Group.	Espenshade, 1954; Brown, 1958; 1969; 1970; Redden, 1963; Conley; 1978; Evans, 1984
Alligator Back Fm.	Southwestern Virginia to northwestern North Carolina	Thin-bedded metagraywacke and schist with intercalated amphibolite and ultramafic rocks	Deep-water; interfingers with Evington Group	Rankin and others, 1973; Rankin, 1975
		Upper Proterozoic Rocks (690-570 Ma) (no relative order implied)		
Catoctin Fm.	Southern Pennsylvania to central Virginia	Metabasalt with interbedded clastic rocks; local occurrences of agglomerates and pillow basalts; rhyolite abundant in southern Virginia	Submarine extrusion dominant in Virginia	Furcron, 1939; 1969; Brown, 1958, 1970; Nelson, 1962; Espenshade and Clarke, 1976; Conley, 1978; Evans, 1984
Mechum River Fm.	Northern and central Virginia	Feldspathic sandstone, conglomerate, and slate in an elongate belt 1-2 km wide	Alluvial sedimentation in elongate graben (Schwab, 1974), or western inlier of Lynchburg Gp. (Brown, 1973)	Gooch, 1958; Allen, 1963; Brown, 1970; 1973; Schwab, 1974
Lynchburg Gp. / Fm.	Central Virginia	Feldspathic metagraywacke, siltstone and graphitic schist with minor conglomerate, quartzite, and marble; amphibolite dikes in lower part, ultramafic rocks in upper part	Turbidite and related deep-water sedimentation predominant; lower sequence to north represents alluvial-fan-slope; local glacial influence	Brown, 1958; 1970; Nelson, 1962; Conley, 1978; Wehr, 1983
Ashe Fm.	Southwestern Virginia to northwestern North Carolina	Metagraywacke, schist, amphibolite, and ultramafic rocks	Deep-water deposition and submarine volcanism; southern equivalent of Lynchburg Gp.	Rankin, 1970; 1975; Rankin et al., 1973; Hatcher, 1978

FIG. 6-5. - Generalized stratigraphic cross-section showing regional variations in the nature of pre-Chilhowee Group strata (Modified from Schwab, 1972).

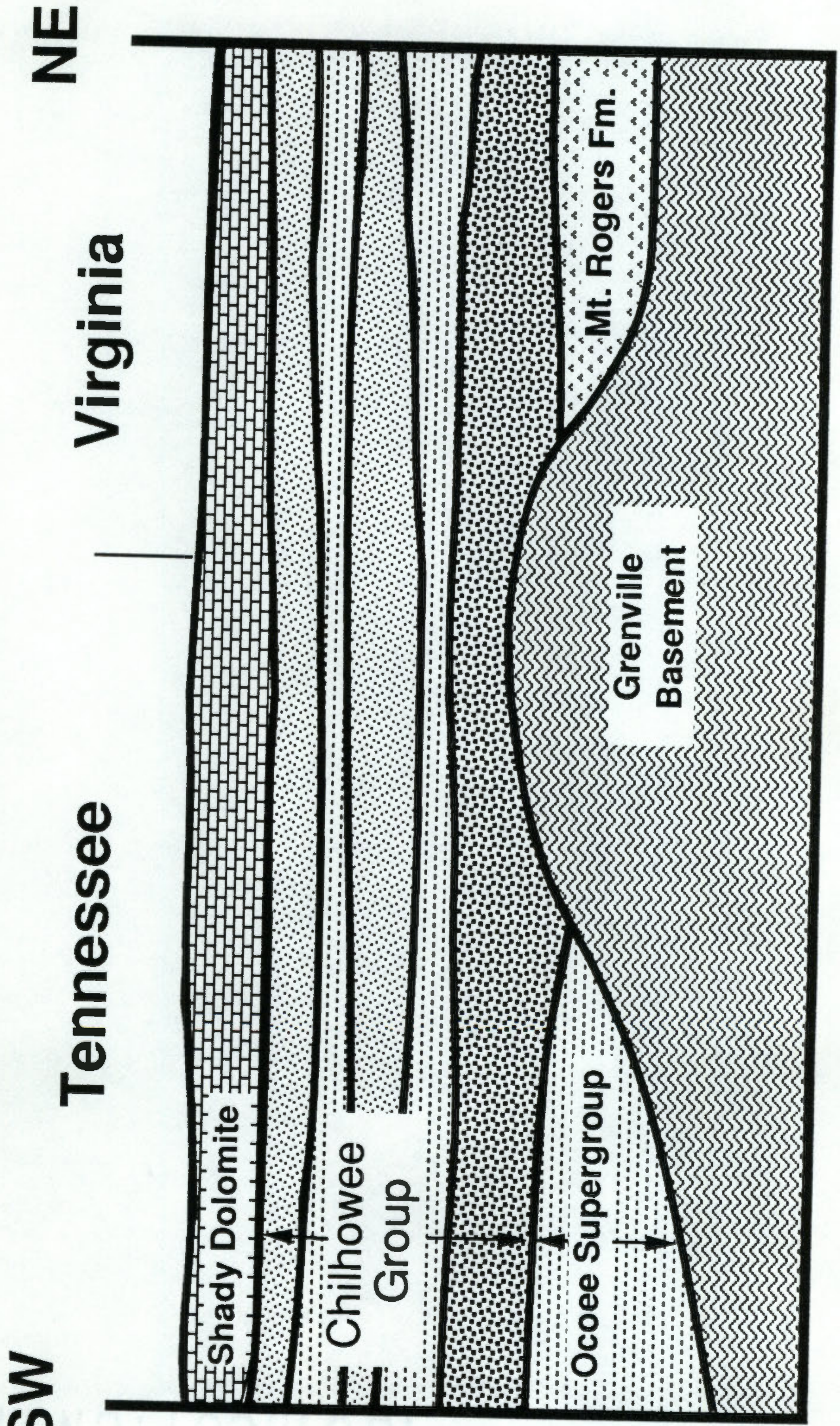

SW
NE
Tennessee
Virginia
Shady Dolomite
Chilhowee Group
Ocoee Supergroup
Mt. Rogers Fm.
Grenville Basement

FIG. 6-6. - Stratigraphy of the Ocoee Supergroup and Mount Rogers Formation (Modified from Hadley and Goldsmith, 1963 and Rankin, 1967).

Latest Proterozoic to Early Cambrian	**Chilhowee Group**		
Late Proterozoic	**OCOEE SUPERGROUP**	Walden Creek Group	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation
		Unclassified Formation	Cades Sandstone; Sandstones of Webb Mountain and Big Ridge; Rich Butt Sandstone
		Snowbird Group	Metcalf Phyllite Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
Middle Proterozoic	Grenville Basement		

Latest Proterozoic to Early Cambrian	**Chilhowee Group**	
Late Proterozoic	**MOUNT ROGERS FM.**	upper member - glaciogenic strata
		middle member - interbedded latites and rhyolites
		lower member - cobble conglomerates with minor basalt and rhyolite
Middle Proterozoic	Grenville Basement	

signatures similar to MORB basalts (Misra and Lawson, in press). Stratigraphically highest (and therefore youngest) of the groups comprising the Ocoee Supergroup is the Walden Creek Group. The Walden Creek Group has been described as the most heterolithic of all of the Ocoee Supergroup (Hadley and Goldsmith, 1963), containing greater than 3 km of dominantly siliciclastic strata. Minor limestone and dolostone intervals (Yellow Breeches member of the Wilhite Formation) may indicate relatively widespread if intermittent carbonate deposition (Hadley and Goldsmith, 1963). Directly above the Wilhite Formation are fine-grained siliciclastic deposits of the Sandsuck Formation (Hadley and Goldsmith, 1963). Late Proterozoic acritarchs have been recovered throughout the Walden Creek Group resulting in its assignment of a Vendian age (Knoll and Keller, 1979;see Chapter 2 for more discussion). Thus the overall stratigraphic architecture of the Ocoee may be interpreted as representing the evolution of a continental rift (Snowbird and Great Smoky Group deposits) to thermal subsiding basin (Walden Creek Group deposits)

Mount Rogers Formation

Unlike the Ocoee Supergroup to the southwest, the Mount Rogers Formation contains large amounts of volcanic and volcano-sedimentary rock. From base to top the Mount Rogers can be characterized as: 1) interbedded basalt, rhyolite and siliciclastic rocks; 2) massive rhyolite flows; and 3) a predominantly sedimentary sequence of arkose, rhythmite, laminated pebbly mudstone and tillite (Rankin, 1970; 1975; Blondeau and Lowe, 1972; Schwab, 1976; Wehr and Glover, 1985). As discussed by Rankin (1968, 1970, 1975, 1976) and Rankin and others (1969) stratigraphic, mineralogic, chemical, and isotopic-geochronologic evidence indicates that the volcanic portion of the Mount Rogers Formation represents a small, distinct portion of the much more regionally extensive bimodal and anoregenic magmatic suite. This suite includes volcanic rocks of the Grandfather Mountain Formations, that together with the Crossnore, Beech, Striped Rock, and other plutons, comprise the 680-720 Ma Crossnore Plutonic Series (Odom and Fullagar, 1984).

The occurrence of cross-stratified feldspathic arenites and pebbly sandstone led Schwab (1976, 1977) to propose an alluvial origin for some deposits within the Mount Rogers Formation. The terrestrial affinity of some portions of the Mt. Rogers is further substantiated by the occurrence of widespread, thick rhyolite ash flows of subaerial origin (Rankin, 1970). Conversely, fine-grained laminated facies and turbidites occur in some portions of the Mount Rogers indicating shallow marine or lacustrine deposition (Wehr and Glover, 1985). The areal discontinuity on the regional scale and the occurrence of an erosional surface of considerable relief strongly suggests that the Mt. Rogers Formation was dominated by deposition in fault bounded basins (Wehr and Glover, 1985).

CHILHOWEE GROUP AND ITS POSSIBLE EQUIVALENTS

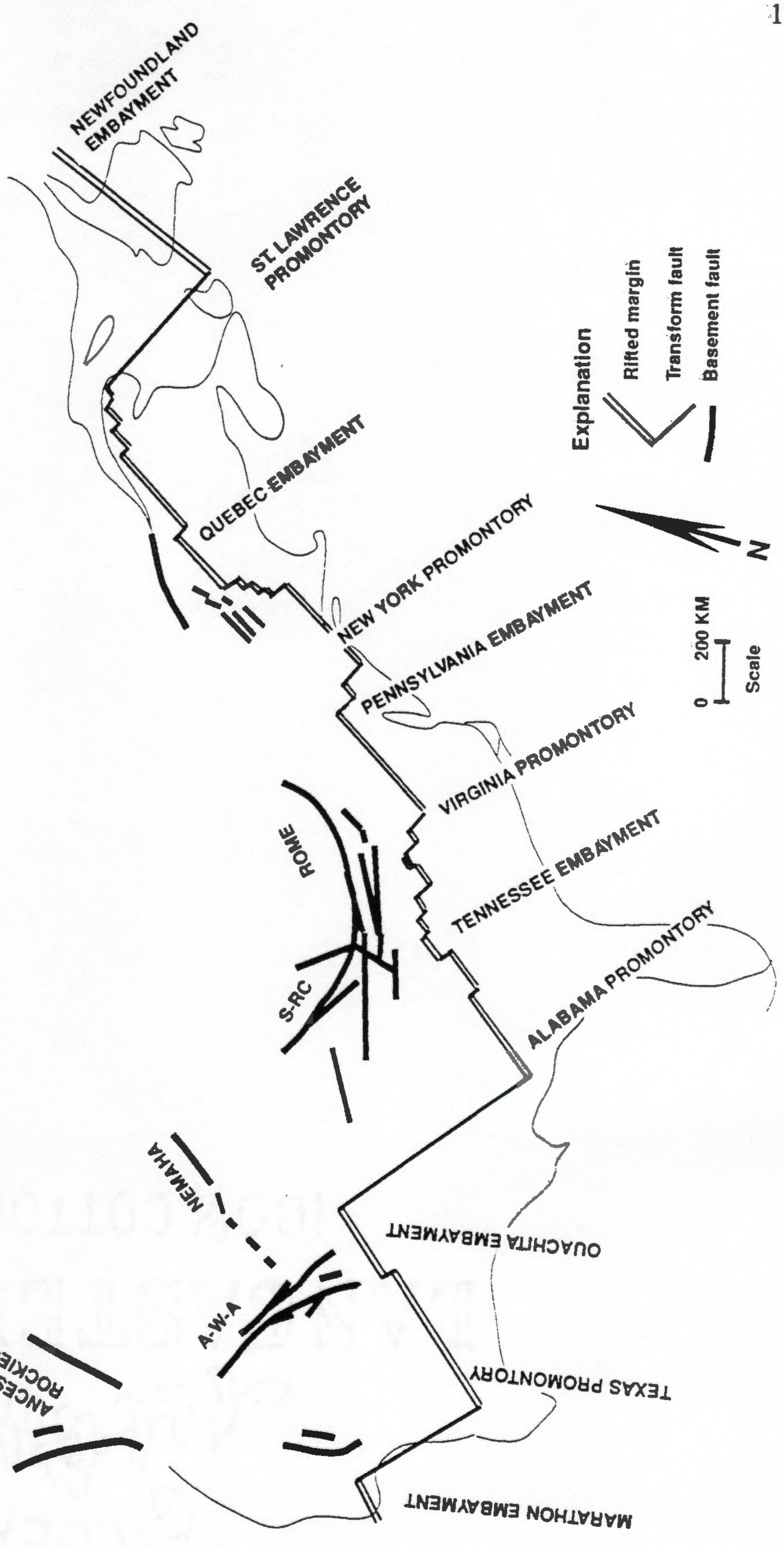
The Chilhowee Group (uppermost Proterozoic to Lower Cambrian) is exposed in discontinuous strike-belts from Alabama to Newfoundland (Schwab, 1972; Mack, 1980). In the southern Appalachians, it is restricted to the western margin of the Blue Ridge and the immediately adjacent portion of the Valley and Ridge (Fig. 6-1) and consequently possesses a complex stratigraphic nomenclature (Fig. 6-2). Although the nomenclature varies along its present geographic trend some salient features have been reported by previous workers, which can be used to make some preliminary conclusions about its general tectonic and stratigraphic significance (Schwab, 1972; Whisonant, 1974; Mack, 1980; Fichter and Diecchio, 1986; Skelly, 1987; Cudzil and Driese, 1987; Simpson and Eriksson, 1989, 1990).

Chilhowee Group of the southern Appalachians

In the southern Appalachian region the Chilhowee Group is a 600-1200 m thick sequence of interbedded feldspathic conglomerate, feldspathic and quartzose sandstone, micaeous siltstone and shale (Schwab, 1970, 1971, 1972; Whisonant, 1974; Mack, 1980; Cudzil and Driese, 1987; Skelly, 1987, Simpson and Eriksson, 1989, 1990, see Chapter 3 for more discussion). Chilhowee rocks in this area have been interpreted as representing the transition from sedimentation within a continental rift / incipient ocean system (Ocoee Supergroup, Grandfather Mountain , Ashe, and Alligator Back Formations), to a passive-margin setting, in association with the opening of the Iapetos (Proto-Atlantic) ocean (Table 6-1; Hatcher, 1972, 1978; Rankin, 1975, 1976). The basal Chilhowee Group overlies the Mount Rogers Volcanic Group, (central and southern Virginia), crystalline Grenvillian age basement (southwestern Virginia and northeastern Tennessee), and the Ocoee Supergroup (southern and central East Tennessee; Fig. 6-6) and is comprised of the Cochran (southern belts) and Unicoi Formations (northern belts). As stated previously, this lower interval probably represents deposition on attenuated continental crust along a thermally subsiding continental margin (southern belts) and or in response to active crustal extension (northern belts; see Chapter 5 for more discussion). The regional distribution of Grenvillian basement and variation in sediment thickness described above, as well as later Paleozoic deformational patterns led Rankin (1975, 1976) and Thomas (1977, 1983) to propose that extension associated with the inception of the Iapetos ocean during the Late Proterozoic and Early Cambrian resulted in an irregular continental margin with associated isolated microcontinents (e.g., internal massifs of the Pine Mountain block and the Sauratown Mountain window; Thomas, 1977; Hatcher, 1987; Walker and others, 1989, see Chapter 4 for more discussion). In the terminology proposed by Thomas (1983) the present-day recesses and salients recognizable in the map pattern of the Appalachian orogen coincide with promontories and embayments (respectively) in the early Paleozoic Laurentian margin (Fig. 6-7). Deposition of the overlying Hampton / Erwin and equivalent formations has been interpreted to have taken place on a stabilized, slowly subsiding continental margin (Fichter and Diecchio, 1986). Paleocurrent data from numerous sources indicate a predominantly westward source (Fig. 6-4), with material prograding eastward over the newly formed continent-ocean boundary (Schwab, 1970; 1971; 1972; Brown, 1970; Whisonant, 1970; Mack, 1980; Cudzil, 1985; Skelly, 1987; Cudzil and Driese, 1987). Previous workers have interpreted the basal Chilhowee units as representing fluvial or coastal alluvial sedimentation, whereas the upper units have been interpreted as representing shallow-marine deposition (Schwab, 1970, 1972; Whisonant, 1974; Mack, 1980; Skelly, 1987; Cudzil and Driese, 1987; Simpson and Eriksson, 1990, see Chapter 3 for more discussion).

Chilhowee Group of Alabama and Georgia. The Chilhowee Group of Alabama and Georgia, as described by Mack (1980), is exposed in a series thrust sheets, west of the Cartersville (Great Smoky) Thrust (sections 1-12, Fig. 6-1). The nature of the local structural style results in significant lack of exposure in the Cochran / Unicoi interval, and a total absence of exposure of the basal contact. Stratigraphic relationships are further obscured by local folding and faulting.

FIG. 6-7. - Outline map of promontories and embayments of late Precambrian - Paleozoic continental margin of eastern North America, interpreted as bounded by rift and transform faults. Margin morphology based on trace of Appalachian - Ouachita orogenic belt and on distribution of thickness and facies of Upper Proterozoic and Paleozoic sedimentary and volcanic rocks (Thomas, 1977). Intracratonic basement fault systems: A-W-A = Arbuckle-Wichita-Amarillo (southern Oklahoma); S-RC = Shawneetown-Rough Creek (From Thomas, 1983).


NEWFOUNDLAND EMBAYMENT
ST. LAWRENCE PROMONTORY
QUEBEC EMBAYMENT
NEW YORK PROMONTORY
PENNSYLVANIA EMBAYMENT
VIRGINIA PROMONTORY
TENNESSEE EMBAYMENT
ALABAMA PROMONTORY
ROME
S-RC
NEMAHA
A-W-A
ANCESTRAL ROCKIES
OUACHITA EMBAYMENT
TEXAS PROMONTORY
MARATHON EMBAYMENT
Explanation
Rifted margin
Transform fault
Basement fault
N
0
200 KM
Scale

Chilhowee Group of Virginia. The Chilhowee Group of Virginia, as described by Simpson and Eriksson (1990), is exposed in several thrust sheets along the eastern margin of the Virginia portion of the Blue Ridge litho-stratigraphic province (Fig. 6-1). The nature of exposure, while allowing for some palinspastic separation of measured sections perpendicular to depositional strike, results in the less than optimum conditions necessary for a systematic study of margin evolution. Twelve sections (numbered 20-31, Fig. 6-1) were measured and described, allowing for the delineation of several progradational / transgressive sequences within the Chilhowee Group. The recognition of these sequences is important in that the interplay between subsidence and sedimentation is more complex than may have originally been hypothesized. Since the pattern of sedimentation does not follow that generally recognized for a thermally subsiding margin, some influence of sea-level change must be present (Simpson and Eriksson, 1990; see Chapter 3 for more discussion).

Chilhowee Group of Eastern Tennessee. The more complete exposures of the Chilhowee Group in this area provide greater opportunity to observe changing sedimentation patterns during the stabilization of the Iapetos margin. The Chilhowee Group in this area has been sub-divided into six formations (Sections 13-19, Fig. 6-1). The basal unit in this area is the Cochran-Unicoi Formation, which ranges in thickness from 100-200 m in the central and southern outcrop belts to as much as 400 m in northeastern Tennessee (see Chapter 3 and 5 for more discussion). Conglomerate and pebbly sandstone are abundant towards the base and grade upward into very coarse-grained feldspathic sandstone (with feldspar content generally decreasing upsection; Whisonant, 1974; see Chapter 5 for more discussion). Sedimentary structures observed include fining-upward conglomeratic beds and low-angle, planar tabular, cross-stratified sandstone (see Chapter 3 for more discussion). Paleoenvironmental interpretations ranging from fluvial to marginal-/and shallow marine have been proposed (Schwab, 1971; Whisonant, 1974; Skelly, 1987; Cudzil and Driese, 1987; Simpson and Eriksson, 1990; see Chapter 3 for more discussion).

Conformably overlying the Cochran-Unicoi interval are 75-275 m of the Nichols and Hampton Formations (Cudzil, 1985; Skelly, 1987; Cudzil and Driese, 1987; see Chapters 2 and 3 for more discussion). This stratigraphic interval consists of thin-bedded mudstone, interstratified with some thin feldspathic glauconitic sandstone and siltstone beds containing *Skolithos* traces observable at the type locality at Chilhowee Mountain (see Chapters 2 and 3 for more discussion). The Nichols-Hampton interval has been interpreted as representing shallow-marine shelf, shoreface, littoral, and tidal flat (*Skolithos* burrowed sandstone) deposition (Whisonant, 1974; Cudzil and Driese, 1987; see Chapter 3 for more discussion).

The Nebo Formation (Member of the Erwin Formation in northeast Tennessee) overlies the Nichols-Hampton interval and ranges from 20-120 m in thickness (Cudzil, 1985; Skelly, 1987; Cudzil and Driese, 1987; see Chapter 2 and 3 for more discussion). It is dominantly a medium-grained, submature quartz arenite to feldspathic arenite (Whisonant, 1974). Sedimentary structures include horizontal stratification, low-angle planar-tabular cross-stratification, and locally abundant *Skolithos* traces (see Chapter 2 for more discussion). Previously proposed depositional environments include beach, barrier island, and intertidal to subtidal bars; wave-, longshore current- and tidal-influences are all inferred (Whisonant, 1974; Cudzil and Driese, 1987; see Chapter 3 for more discussion).

The Murray Formation (Member of the Erwin Formation in northeast Tennessee) conformably overlies the Nebo Formation and ranges from 75-105 m in the central and southern area (Skelly, 1987) to about 220 m in northeastern Tennessee (Cudzil and Driese, 1987). It consists of thin-bedded mudstone, which is interstratified with some thin-bedded feldspathic glauconitic sandstone and siltstone beds, which have yielded Rb-Sr dates of 539 ± 30 Ma. (Hurley and others, 1960; Courmier, pers. comm., 1990; see Chapter 2 for more discussion). Rare lingulellid brachiopods, trilobites and ostracodes have been reported (Laurence and Palmer, 1963). Murray Formation depositional environments are inferred to have been similar to earlier Nichols-Hampton conditions (Whisonant, 1974; Cudzil and Driese, 1987; see Chapter 3 for more discussion).

Conformably overlying the Murray Shale occurs 40-100 m of the Hesse Formation (Member of the Erwin Formation in northeast Tennessee; Skelly, 1987; Cudzil and Driese, 1987; see Chapters 2 and 3 for more discussion). The Hesse Formation consists of fine- to medium-grained, submature to mature quartz arenite that resembles the older Nebo Sandstone (Whisonant, 1974; see Chapter 3 for more discussion). Sedimentary structures observed within the Hesse Formation include horizontal stratification, planar-tabular cross-stratification, wave and current ripple marks, loading structures and locally abundant *Skolithos* traces. Hesse Formation depositional environments are inferred to have been similar to earlier Nebo conditions (Whisonant, 1974; Cudzil and Driese, 1987; see Chapter 3 for more discussion).

The uppermost portion of the Chilhowee group in this area consists of the 15-60 m of the Helenmode Formation (Member of the Erwin Formation in northeast Tennessee) (King and Ferguson, 1960; King, 1964; Neuman and Nelson, 1965; Cudzil, 1985; Cudzil and Driese, 1987). The Helenmode Formation (Member) consists of poorly exposed calcareous shale, siltstone and sandstone (Whisonant, 1974; Cudzil and Driese, 1987; see Chapter 2 for more discussion). Occurrences of inarticulate brachiopods, trilobites, hyolithids and ostracodes have been reported (Neuman and Nelson, 1965). The Helenmode is inferred to have been deposited during transition from the terrigenous clastic-dominated Chilhowee shelf to the Shady Dolomite carbonate shelf (Whisonant, 1974; Cudzil and Driese, 1987).

Chilhowee Group of the Eastern Blue Ridge and Possible Equivalent Strata

As stated by Hatcher (1987) the Proterozoic (1.1 b.y.) Grenvillian crystalline rocks form the autochothonous North American reference frame, since they serve as the basement upon which many of the upper Proterozoic and younger stratigraphic packages were deposited. Several structural windows occur within the Blue Ridge and Piedmont which expose crystalline basement and their autochthonous lower Paleozoic cover sequences (Figs. 6-3 and 6-8). Chief among these are the Grandfather Mountain (North Carolina), Sauratown Mountain (North Carolina), and Pine Mountain (Alabama and Georgia) windows (Reed and Bryant, 1960; Bryant and Reed, 1963, 1970; Heyn, 1984; Hooper, 1986; Hatcher and others 1986; Hatcher, 1987, 1989).

Grandfather Mountain window. The southwestern portion of the Grandfather Mountain Window exposes a second thrust sheet termed the Table Rock Thrust by Bryant and Reed (1970). This thrust sheet forms a prominent klippe which caps Tablerock Mountain, and contains an extensive interval of quartzite, feldspathic quartzite, and phyllite, which has been assigned to the Chilhowee Group based on lithologic and stratigraphic similarity (Bryant and Reed, 1970). Because of its isolated tectonic position, rocks of the Tablerock Thrust sheet have not been correlated with

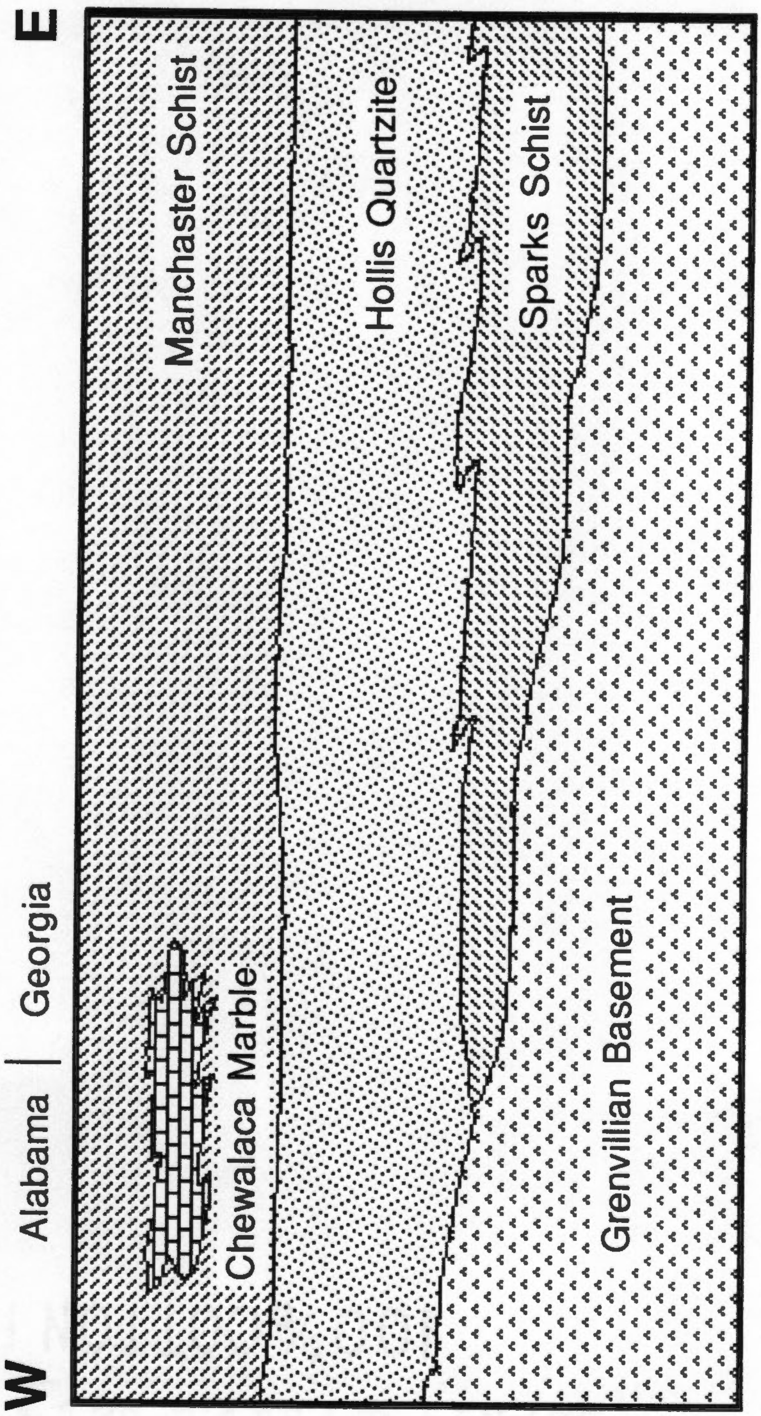
FIG. 6-8. - Stratigraphic nomenclature of possible Chilhowee Group equivalents of the Eastern Blue Ridge and Inner Piedmont. Note: Stratigraphic correlation shown here is speculative and has yet to be confirmed, see text for discussion (Compiled from Bryant and Reed, 1970; Schwab, 1977; Hooper, 1986; Heyn, 1984).

AGE		Grandfather Mountain, NC	Pine Mtn. Belt Ala / Ga		Sauratown Mtns., NC
EARLY CAMBRIAN		Shady Dolomite	Manchester Formation	Chewalaca Marble	absent
	CHILHOWEE GROUP	upper quartzite		interbedded quartzite and schist	quartzite of Pilot Mtn. and Hanging Rock
		phyllite			pelitic schist and phyllite
		lower quartzite	Hollis Quartzite		quartzite and feldspathic quartzite / arkose
MIDDLE OR LATE PROTEROZOIC		truncated by Tablerock thrust	Woodland Gneiss (Alabama)	Sparks Schist (Georgia)	Grenvillian Basement

specific formations within the Chilhowee Group of the western Blue Ridge. Bryant and Reed (1970) therefore, subdivided the sequence into two quartzites, separated by a persistent blue phyllite. The Lower Quartzite varies from 250 m to 700 m in thickness and contains medium- fine-grained quartzite feldspathic quartzite with numerous interbeds of green sericite phyllite. Interbedded within the quartzite and feldspathic quartzite are intervals of quartz-pebble and feldspar-pebble conglomerate reminiscent of the basal members of the Chilhowee Group of the western Blue Ridge. Overlying the Lower Quartzite, occur rocks of the Phyllite Unit which are described as finely laminated, dark blue-gray to blue, sericite with thin lenses of granoblastic quartz. The thickness of this unit is extremely variable, ranging form a few meters to as much as 130 m, with an average thickness of less than 50 m. The uppermost unit within the Chilhowee Group in the area (termed the Upper Quartzite), is comprised of 400 - 800 m of thin- to thick-bedded, fine- to medium-grained quartzite and feldspathic quartzite, containing occasional intervals of deformed *Skolithos* tubes, and is conformably overlain by rocks of the Shady Dolomite. Cross-bedding, defined by heavy mineral lamination, occurs throughout the Chilhowee Group and may lend evidence for further correlation, via facies analysis and heavy mineral association.

Pine Mountain window. The Pine Mountain window is structurally complex, framed in part by the pre-metamorphic Box Ankle Fault, the post-metamorphic Towaliga Fault, and the syn- to post-metamorphic Goat Rock-Bartletts Ferry fault (Schamel and Bauer, 1980; Sears and Cook, 1984; Hooper, 1986; Hatcher and others, 1986; Hatcher, 1987, 1989). Within the window, Grenvillian age basement is overlain by a thin cover sequence composed of the Hollis Quartzite, Sparks and Manchester Schists and Chewacla Marble (Clarke, 1952; Bentley and Neathery, 1970; Fig. 6-8) which comprise the Pine Mountain Series (Hooper, 1986), resulting in many workers hypothesizing a stratigraphic correlation with the Chilhowee-Shady-Rome interval of the western Blue Ridge (Rankin, 1975, 1976; Thomas, 1977, 1983; Hatcher, 1987). The stratigraphic distribution of schists and marble within the area, seem compatible with a westward sediment source, further substantiating the hypothesized Chilhowee Group affinity for the Pine Mountain Series (Fig. 6-9). While the deformation within the area is pervasive, some primary sedimentary structure is preserved within Manchester Schist (Clarke, 1952), which may

FIG. 6-9. - Generalized stratigraphic cross-section for the Pine Mountain Belt, Alabama and Georgia (Compiled from Clarke, 1952; Bentley and Neathery, 1970; Hooper, 1986).


W
E
Alabama
Georgia
Manchaster Schist
Chewalaca Marble
Hollis Quartzite
Sparks Schist
Grenvillian Basement

be of some utility in determining the paleogeographic and paleoenvironmental history of the area.

Sauratown Mountain window. Framed by the Forbush Fault, a pre-metamorphic fault which may be a southeastern equivalent of the Hayesville-Fries thrust, the Sauratown Mountain Window contains a second inner window (termed the Hanging Rock Inner Window by Hatcher and others, 1988), which exposes Grenvillian crystalline basement and it's associated cover sequence (Bryant and Reed, 1960; Hatcher, 1987). This cover sequence consists of a basal arkosic unit, overlain by phyllite and muscovite schist, which in turn is overlain by a quartzite which forms the prominent cliffs of Pilot Mountain and Hanging Rock Bluff (Fig. 6-8; Bryant and Reed, 1963; Walker and others, 1989; see Chapter 4 for more discussion). While the gross stratigraphic succession resembles that of the Chilhowee Group of the western Blue Ridge, the deformation and metamorphism in the area have hindered attempts to correlate these two successions. Comparison of depositional processes and stratigraphic thicknesses of similar lithologies observed at Pilot Mountain and near Valley Forge, Tennessee do not appear to be consistent with the interpretation of the quartzite of Pilot Mountain as representing some eastern equivalent of the Chilhowee Group of East Tennessee (see Chapter 4 for more discussion). The observed lithostratigraphic similarity between these two sequences may be a manifestation of similarities of source rock and depositional setting. Whereas chronostratigraphic equivalence may not be applicable, this type of similarity would be consistent with interpretation of the quartzite at Pilot Mountain as representing deposition along an offshore, rifted microcontinent or similar terrane, as proposed by Thomas (1977).

Because the entire Pilot Mountain sedimentary sequence rests on Grenville basement (Hatcher, 1984, 1987; Hatcher and others 1988; McConnell and others, 1986), North American affinity appears certain. Palinspastic reconstruction of the southern Appalachian orogen indicates that the sedimentary sequences exposed within the Sauratown Mountains window, the Grandfather Mountain window, and the Unaka belt occupy the same *relative* positions (with respect to the Laurentian continental margin) today as they did when they were first deposited. The quartzites exposed within the Sauratown Mountains window probably represent either Late Proterozoic or Early Cambrian deposition along a sea-floor high associated with an isolated basement terrane during early marine incursion into the late rift or early drift phase Iapetos basin (see Chapter 4 for more discussion).

EVOLUTION OF THE LAURENTIAN- IAPETOS MARGIN

Consideration of the stratigraphic and geochronological elements presented previously results in the formulation of the following tentative history for the evolution of the North American - Iapetos continental margin.

1) Grenville Orogeny (1.1 Ga)

2) Initiation of thermal perturbation and injection of Crossnore Plutonic Series (710-690 Ma.) and possible coeval development of a system of asymmetric, alternately facing half-grabens. The North American representatives of this basin system would then include the Ocoee Supergroup and the Mt. Rogers, Grandfather Mountain , Swift Run, and Mechum River Formations.

3) Cessation of thermal activity resulted in a transition from active volcanism and crustal extension to a period of tectonic quiescence. This stage is then recorded by the fine grained siliciclastic and carbonate lithologies of the Walden Creek Group (Tennessee embayment) and the glaciogenic sediments of the upper Mount Rogers Formation (Virginia promontory).

4) Renewed thermal activity results in renewed volcanic activity (recorded by basalts of the Unicoi and Catoctin Formation) and uplift recorded by alluvial-fan and fluvial strata of the Cochran and Unicoi Formations.

5) Continued extension results in initiation of oceanic crust formation along one or more spreading centers east of the Ocoee and Mount Rogers depositional basins. Continuing extension results in the formation of a basin of adequate width to posses a primitive continental slope and rise system represented by the Lynchburg and Ashe Formations of the eastern Blue Ridge (690 - 570 Ma). The emplacement of oceanic crust then marks the inception of the Iapetos ocean.

6) Subsidence, most likely attributable to thermal processes and coincident with Early Cambrian sea-level rise, results in the deposition of an overall transgressive sequence, represented by the upper 2/3 of the Chilhowee Group (Hampton - Erwin equivalents). Interplay between subsidence and eustacy results in periodic progradation of shoreline sediment and the burial of basal Chilhowee

"paleohighs". This change in margin configuration is evidenced by the general change from a paleoflow system dominated by point source to one characterized by uniform easterly flow (539 ± 30 Ma).

7) Stabilization of the margin and consequent reduction in terrigenous influx results in the development of a widespread carbonate shelf system represented by the Shady Dolomite and equivalent strata.

SUMMARY

Although the state of our understanding of the stratigraphic evolution of upper Proterozoic and Lower Cambrian strata of the Blue Ridge of the southern Appalachians has greatly expanded in recent years, much is yet to be learned about this truly complex system. A review of articles published over just the last 20 years would be very extensive and beyond the scope of this paper. The salient points mentioned previously, however, when considered in the new light shed by recent studies of modern tectonic analogues provide improved understanding of the evolution of Iapetos Margin as recorded by the Chilhowee Group in the southern Appalachians . Dominate among these is the concept that factors inherited from the "rift" phase greatly influence "drift" depositional and stratigraphic patterns, including:

1) along strike changes in basement configuration (Chapters 3 and 5)
2) point source vs. line source paleocurrent patterns (Chapter 3)
3) variation in stratigraphic thicknesses (possibly due to variation in subsidence related to regional differences in the timing and degree of crustal attenuation; Chapter 3 and 5)
4) regional distribution of depositional environments (Chapter 3)
5) regional variation in the framework grain mineralogy of basal Chilhowee Group sequences (Chapter 5).

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APPENDICES

APPENDIX A

MEASURED SECTION DESCRIPTIONS

The study area included 6 exposures of Chilhowee Group strata includinmg: Bean Mountain (35° 07' 30" N latitude, 84° 37' 30" W longitude), Chilhowee Mountain - Walland locality (36° 8' 30" N latitude and 83° 35' 30" W latitude), Chilhowee Mountain -Murray Gap locality (36° 7' 00" N latitude and 83° 37' 30" W latitude), English Mountain (36° 6' 00" N latitude and 82° 16' 00" W longitude), I-40 (36° 5' 30" N latitude and 82° 14' 00" W longitude), Valley Forge (36° 18' 00" N latitude and 82° 11' 00" W longitude), and Hampton (36° 15' 30" N latitude and 82° 9' 30" W longitude). Of these exposures, 4 were measured and described as part of this study. The following measured section descriptions were completed in the field at the Chilhowee Mountain, English Mountain, I-40, and Hampton exposures.

Bedding thickness and cross-set thickness nomenclature are as follows (Ingram, 1954):

Bedding	Cross-stratification	Thickness(m)
Very thick-bedded		> 1.0
Thick-bedded	Large-scale	0.3 - 1.0
Medium-bedded	Medium-scale	0.1 - 0.3
Thin-bedded	Small-scale	0.03 - 0.1
Very thin-bedded		0.01 - 0.03
Laminated		0.003 - 0.001
Thinly laminated		<0.003

Grain-size descriptions using the classes of Wentworth (1922):

Size Class	Diameter (mm)
Pebbles	4.0 - 64.0
Granules	2.0 - 4.0
Very coarse sand	1.0 - 2.0
Coarse sand	0.5 - 1.0
Medium sand	0.25 - 0.5

Fine sand	0.125 - 0.25
Very Fine sand	0.0625 - 0.125
Silt	< 0.0625

UNIT	THICK. (m)	CUMM. THICK. (m)	DESCRIPTION
Chilhowee Mountain Section (Walland)			Cochran Formation (base of Cochran faulted out by Great Smoky fault at this locality)
1	0.9	0.9	Poorly exposed, medium- to large-scale trough? cross-stratified (1.5 x 0.6 m) coarse-grained to granular feldspathic sandstone. Thin, very fine-grained sandstone to siltstone partings marking upper bounding surface. SAMPLE W-1 taken at 0.06 m above base of section.
2	2.5	3.4	Poorly exposed, medium-bedded (0.6 m average), medium-grained feldspathic sandstone. Internal stratification apparently composed of centimeter thick horizontal lamination. Master bedding thickens and thins laterally.
3	0.6	4.0	Thin-bedded, medium- to coarse-grained feldspathic sandstone with minor (<10%) granular fraction. Bedding appears to thicken and thin laterally. Weathers to distinctive cobbly appearance.
4	1.4	5.4	Very thick-bedded (single bed), massive, coarse-grained to pebbly feldspathic sandstone. Pebbles composed of milky quartz.
5	0.6	6.0	Medium-scale, trough cross-stratified, medium-grained to granular, feldspathic sandstone. Base of individual beds marked by occasional lenses of well-rounded, milky quartz cobbles. Unit appears to fine upward.
6	1.1	7.1	Medium-bedded, medium-grained to pebbly, feldspathic sandstone. Unit appears to thicken and thin laterally. SAMPLE W-2 taken at 7.0 m above base of section.

7	0.4	7.5	Thin- to medium-bedded, coarse-grained to granular, feldspathic sandstone. Internal stratification apparently composed of centimeter thick horizontal lamination or low-angle cross-stratification. Tops of individual beds commonly marked by centimeter thick silt- or mudstone partings. Beds thicken and thin laterally.
8	1.1	8.6	Massive, very thick bedded, coarse-grained to granular, feldspathic sandstone. Unit appears to thicken and thin laterally. Several 2-3 cm diameter cobbles white or milky quartz occur at base.
9	0.4	9.0	single, thick bed of medium-grained to granular, feldspathic sandstone.
10	1.2	10.2	Massive, thick to very thick bedded, poorly sorted, medium-grained to granular, feldspathic sandstone. Beds thicken and thin laterally and may be horizontally laminated.
11	2.5	12.7	Medium- to thick-bedded, medium-grained to granular feldspathic sandstone. Beds thicken and thin laterally. Thin-bedded units weather to a more cobbly appearance.
12	1.0	13.7	Medium-bedded, medium- to coarse-grained, pebbly feldspathic sandstone. Pebbles are typically white or milky quartz. Beds thicken and thin laterally and coarser units appear to have a trough-like morphology.
13	1.5	15.2	Massive, medium- to thick-bedded, coarse-grained feldspathic sandstone to granule/pebble conglomerate. Coarser fraction appears to be milky quartz. Obvious medium-scale trough morphology apparent with troughs possessing width to height ratios of 3 to 1.

14	1.4	16.6	Massive, medium- to thick-bedded, coarse-grained feldspathic sandstone to granule/ milky quartz pebble conglomerate. Medium-scale trough morphology apparent with troughs possessing width to height ratios of 3 to 1.
15	1.3	17.9	Medium- to thick-bedded, coarse-grained feldspathic sandstone to granule/ milky quartz pebble conglomerate. Medium-scale trough cross-stratification apparent with troughs possessing width to height ratios of 3 to 1.
16	.9	18.8	Massive, medium- to thick-bedded, coarse-grained feldspathic sandstone to granule/ milky quartz pebble conglomerate. Medium-scale trough cross-stratification apparent with troughs possessing width to height ratios of 3 to 1. SAMPLE W-3 taken at base.
17	.8	19.6	Massive, very thick bedded, medium- to coarse grained feldspathic sandstone.
18	.7	20.3	Medium- to thick-bedded, coarse-grained feldspathic sandstone to granule/pebble conglomerate. Coarser fraction appears to be milky quartz. Medium-scale trough cross-stratification apparent with troughs possessing width to height ratios of 8-1. Unit capped by single thin bed, possibly planar-tabular cross-stratified, medium-grained feldspathic sandstone.
19	.7	21.0	Medium-bedded, medium-grained feldspathic sandstone. Medium-scale trough cross-stratification apparent with troughs possessing width to height ratios of 3 to 1. Unit appears to coarsen upward.
20	.2	21.2	Thin-bedded to horizontally laminated, fine-grained, quartzose to feldspathic

			sandstone. Base of unit appears to be scour, unit thins laterally to O m. SAMPLE W-4 taken at base.
21	.3	21.5	Medium-bedded, poorly sorted, medium- to coarse-grained, milky quartz pebbly feldspathic sandstone. Small-scale trough cross-stratification apparent.SAMPLE W-5 taken at top/
22	.2	21.7	Thin-bedded, fine- to medium grained feldspathic sandstone. Small-scale trough cross-stratification apparent. Unit pinches out laterally.
23	1.2	22.9	Medium-bedded, coarse-grained feldspathic sandstone to milky quartz pebble conglomerate. small-scale trough cross-stratification apparent.
24	.1	23.0	Horizontally laminated, very fine-grained sandstone to silty shale. Unit pinches out laterally.
25	1.0	24.0	Medium- to thick bedded, poorly sorted coarse-grained feldspathic sandstone to milky quartz pebble conglomerate. Medium-scale trough cross-stratification apparent.
26	.7	24.7	Massive, medium- to coarse-grained feldspathic sandstone to granule conglomerate.
			fault with minor displacement
27	.5	25.2	Thin- to medium bedded, medium-grained feldspathic sandstone to milky quartz granule conglomerate. Small-scale trough cross-stratification apparent, unit appears to fine upward.
28	1.2	26.4	Massive, very thick-bedded, poorly sorted, coarse-grained feldspathic sandstone to gray and milky quartz granule and pebble conglomerate. Largest pebbles measure 1-2 cm in diameter.

29	.7	27.1	Medium-bedded, poorly sorted, gray and milky quartz granule to pebble conglomerate (matrix of fine grained feldspathic sand). Medium-scale trough cross-stratification apparent, with troughs possessing width to height ratios of 8 to 1.
30	.3	27.4	Massive, medium-bedded, poorly sorted, gray and milky quartz granule to pebble conglomerate (matrix of fine grained feldspathic sand).
31	.6	28.0	Medium-bedded, poorly sorted, gray and milky quartz granule to pebble conglomerate (matrix of fine grained feldspathic sand). Small-scale trough cross-stratification apparent, with troughs possessing width to height ratios of 6 to 1.
32	.4	28.4	Massive, medium-bedded, poorly sorted, gray and milky quartz granule to pebble conglomerate (matrix of fine grained feldspathic sand).
33	1.0	29.4	Medium bedded, medium-grained feldspathic sandstone to milky quartz granule and pebble conglomerate. Small-scale trough cross-stratification apparent, unit appears to fine upward. Pebble lenses apparent through defining broad scours possessing width to height ratios of 5 to 1. SAMPLE W-6 taken at base.
34	.3	29.7	Massive, medium-bedded, moderately well-sorted, gray quartz granule conglomerate (grain-supported).
35	1.5	31.2	Interbedded: 1) medium-bedded, medium-grained, feldspathic sandstone; and 2) moderately well-sorted, gray quartz granule conglomerate (grain-supported). Fine grained intervals capped by minor silty shale partings. Distribution of conglomerate suggests scour-fill.

			Base of unit is scour surface. SAMPLE W-7 taken at base.
36	1.0	32.2	Medium bedded, medium-grained feldspathic sandstone to milky quartz granule conglomerate. Small-scale trough cross-stratification apparent, unit appears to fine upward. Granule lenses apparent through defining broad scours possessing width to height ratios of 9 to 1. Unit capped by thin (3 cm) unit of very fine-grained sandstone to silty shale. Unit appears to fine-upward.
37	1.5	33.7	Medium bedded, medium-grained feldspathic sandstone to milky quartz granule conglomerate. Small-scale trough cross-stratification apparent, unit appears to fine upward. Granule lenses apparent through defining broad scours possessing width to height ratios of 9 to 1. Unit capped by thin (3 cm) unit of very fine-grained sandstone to silty shale. Unit appears to fine-upward.
38	.8	34.5	Medium bedded, medium- to coarse grained feldspathic sandstone to milky quartz granule conglomerate. Small-scale trough cross-stratification apparent, unit appears to fine upward. Granule lenses apparent through defining broad scours possessing width to height ratios of 9 to 1. Unit capped by thin (3 cm) unit of very fine-grained sandstone to silty shale. Unit appears to fine-upward. SAMPLE W-8 taken at top.
39	1.2	36.7	Poorly exposed (talus) medium?-bedded, medium- to coarse-grained granular quartzose sandstone. Possible medium-scale trough? cross-stratification barely visible.
40	7.1	42.8	Medium-bedded, well-sorted medium-grained, quartzose sandstone. some individual beds appear to be medium-

			scale trough? cross-stratified, resulting in the entire unit possessing swaley appearance. SAMPLE W-9 taken at middle.
			section continues along ridge above road cut
41	.7	43.5	Poorly exposed (talus), medium- to thick-bedded, medium-grained quartz sandstone.
42	1.0	44.5	Massive, thick-bedded, medium- to coarse-grained, granular quartzose sandstone. Granule lenses may define scours.
43	.6	45.1	Poorly exposed, thin- to medium bedded, medium grained quartzose sandstone. SAMPLE W-10 taken at base.
44	1.0	46.1	Massive, Medium-bedded, medium-grained quartzose sandstone.
45	.8	46.9	Massive, very thick-bedded, medium-grained quartzose sandstone.
46	.5	47.4	Medium-bedded, medium-grained quartzose sandstone.
47	1.0	48.4	Poorly exposed, medium-bedded, quartz granule to pebble conglomerate. Unit fines upward into coarse-grained quartzose sandstone. SAMPLE W-11 taken at top.
48	1.1	49.5	Poorly exposed, medium-bedded, quartz granule to pebble conglomerate. Unit fines upward into coarse-grained quartzose sandstone.
49	.8	50.3	Poorly exposed, medium-bedded, quartz granule to pebble conglomerate. Unit fines upward into coarse-grained quartzose sandstone.

50	.6	51.9	Massive, medium- to coarse-grained quartzose sandstone. Unit may fine-upward slightly.
51	.6	51.5	Massive, medium- to coarse-grained quartzose sandstone. Unit may fine-upward slightly. Base of unit appears to be scoured.
52	.6	52.1	Massive, medium- to coarse-grained quartzose sandstone. Unit may fine-upward slightly. Base of unit appears to be scoured.
53	.6	52.7	Poorly exposed, medium-bedded, quartz granule to pebble conglomerate. Unit fines upward into coarse-grained quartzose sandstone. Some possible small-scale trough cross-stratification apparent.
54	1.3	54.0	Medium-bedded, well-sorted, medium-grained quartzose sandstone. Base and top of unit sharp and planar features. SAMPLE W-12 taken at base.
55	.7	54.7	Medium-bedded, medium-grained quartzose and feldspathic sandstone. Some possible small-scale trough cross-stratification apparent. Unit capped by thin (3 cm) unit of very fine-grained sandstone to silty shale. Unit appears to fine-upward.
56	1.2	55.9	Thin- to medium-bedded, medium-grained quartzose sandstone. Some possible small-scale trough cross-stratification or hummocky stratification apparent. Top of unit sharp and planar.
57	.4	56.3	Poorly exposed (vegetation), thin-bedded, horizontally laminated, micaous to medium-grained feldspathic sandstone. SAMPLE W-13 taken at top.
58	1.5	57.8	Massive, medium-bedded, medium-grained quartzose and feldspathic

			sandstone. Top of unit sharp and planar.
59	1.4	59.2	Medium- to thick-bedded, poorly sorted, quartz granule and pebble conglomerate (matrix of fine grained feldspathic sand). Base of unit marked by broad scour. SAMPLE W-14 taken at base.
60	1.2	60.4	Medium-bedded, coarse-grained to granular feldspathic sandstone. Small-scale trough cross-stratification apparent.
61	.9	61.3	Medium- to thick-bedded, poorly sorted, quartz granule and pebble conglomerate (matrix of fine grained feldspathic sand). Base of unit marked by broad scour.
62	.8	62.1	Medium- to thick bedded, coarse-grained feldspathic sandstone to granule conglomerate. Small-scale trough cross-stratification apparent throughout.
63	1.2	63.3	Poorly exposed (talus), medium-bedded, coarse-grained feldspathic sandstone to granule conglomerate. Possible trough cross-stratification apparent.
64	1.0	64.3	Poorly exposed (talus), medium-bedded, coarse-grained feldspathic sandstone to granule conglomerate. Each bed appears to fine upward.
65	7.5	71.8	covered interval
66	.6	72.4	Medium- to thick-bedded, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Small-scale trough cross-stratification apparent throughout. Unit appears to fine upward into poorly sorted, medium- to coarse grained sandstone. SAMPLE W-15 taken at top.

67	.5	72.9	Thick-bedded, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Unit appears to be horizontally laminated internally.
68	.7	73.6	Massive, medium-bedded, gray quartz granule conglomerate to very coarse-grained sandstone.
69	.8	74.4	Poorly exposed, medium-bedded, coarse-grained, quartzose sandstone.
70	.8	75.2	Medium-bedded, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Small-scale trough cross-stratification apparent throughout. Unit appears to fine upward into poorly sorted, medium- to coarse grained sandstone.
71	.7	75.9	Thick bedded, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Small-scale trough cross-stratification apparent throughout. Unit appears to coarsen upward.
72	.5	76.4	Massive, medium-bedded, coarse-grained quartzose sandstone to pebble conglomerate.
73	1.3	77.7	Thick-bedded, quartz granule to pebble conglomerate. small-scale trough cross-stratification apparent throughout.
74	.3	78.0	Medium-bedded, poorly sorted, coarse-grained feldspathic sandstone to granule and pebble conglomerate. Top of unit sharp and planar.
75	.2	78.2	Interbedded: 1) very thin-bedded, coarse-grained, feldspathic sandstone; and 2) horizontally laminated very fine-grained sandstone. Unit coarsens and thickens upward. SAMPLE W-16 taken from coarser unit near top.

76	1.5	79.7	Medium-bedded, poorly sorted, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Medium-scale trough cross-stratification apparent throughout.
77	1.1	80.8	Medium-bedded, poorly sorted, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Medium-scale trough cross-stratification apparent throughout.
78	.8	81.6	Medium-bedded, poorly sorted, coarse-grained quartzose and feldspathic sandstone to granule and pebble conglomerate. Medium-scale trough cross-stratification apparent throughout.
79	1.0	82.6	Medium-bedded, well-sorted, fine- to medium-grained quartzose and feldspathic sandstone. Unit possibly horizontally laminated to low-angle planar-tabular cross-stratified. SAMPLE W-17 taken near top.
80	.1	82.7	Thin-bedded, poorly-sorted, medium- to coarse-grained, granular, feldspathic and micaous sandstone. Unit apparent horizontally laminated.
81	.6	83.3	Medium-bedded, quartz granule to pebble conglomerate (grain-supported). Small-scale trough cross-stratification may be present.
82	.7	84.0	Poorly exposed, massive, thick-bedded, quartz granule to pebble conglomerate.
83	.8	84.8	Medium-bedded, poorly sorted, coarse-grained to granular, quartzose sandstone. Discreet lenses of granules suggest small-scale troughs cross-stratification or scours. Base and top of unit swaley in appearance.

84	1.0	85.8	Poorly exposed, interbedded: 1)thin- to medium-bedded, well sorted, medium-grained quartzose sandstone; and 2) poorly sorted, coarse-grained to granular feldspathic sandstone. SAMPLE W-19 taken at base.
85	1.5	87.3	Medium- to thick-bedded, poorly sorted, coarse-grained feldspathic sandstone to granular conglomerate. Beds display tabular morphology.
86	1.5	88.8	Medium-bedded, poorly sorted, poorly sorted, coarse-grained feldspathic sandstone to quartz granule - pebble conglomerate. Medium-scale trough cross-stratification apparent throughout.
87	1.5	90.3	Poorly exposed, medium-bedded, poorly sorted, medium-grained to pebbly (with minor quartzose component of pebble fraction) feldspathic sandstone.
88	.5	90.8	Poorly exposed (talus), medium-bedded, well-sorted, medium-grained, quartzose sandstone.
89	1.5	92.3	Massive, medium-bedded, well-sorted, medium-grained, quartzose sandstone.
90	1.3	93.6	Massive, medium- to thick-bedded, moderately well-sorted, medium-grained quartzose and lithic sandstone. SAMPLE W-20 taken at base.
91	.4	94.0	Massive, medium-bedded, well-sorted, medium-grained quartzose sandstone. Individual beds pinch and swell laterally.
92	.2	94.2	Thin-bedded, moderately well-sorted, medium-grained quartzose sandstone. Possible low-angle planar-tabular cross-stratification apparent.

93	.2	94.4	Massive, medium-bedded, well-sorted, medium-grained quartzose sandstone.
94	.2	94.6	Poorly exposed, thin-bedded, medium- to coarse-grained, feldspathic sandstone. Unit pinches and swells laterally.
95	1.5	96.1	Thin- to medium-bedded, well sorted, fine- to medium-grained quartzose sandstone. Low angle, planar-tabular cross-stratification apparent throughout. SAMPLE W-21 taken near center.
			Base of Nichols Formation.
96	3.0	99.1	Horizontally laminated, dark gray to black silty shale with minor 2-3 cm thick siltstone to very fine-grained sandstone beds present at base.
97	3.0	102.1	Horizontally laminated to very thinly bedded, dark gray to black silty shale.
98	2.8	104.9	Horizontally laminated to very thinly bedded, medium-gray silty shale with minor 2-3 cm thick siltstone to very fine-grained sandstone beds present at top.
99	2.3	107.2	Horizontally laminated to very thinly bedded, gray-brown to brown silty shale (weathers dark brown).
100	8.0	115.2	Covered interval (talus).
101	.4	115.6	Very thin-bedded to horizontally laminated shaly siltstone to silty shale.
102	1.5	117.1	Interbedded: 1) very thin-bedded, medium-gray silty shale; and 2) horizontally laminated to thin-bedded fine-grained quartzose sandstone. SAMPLE W-22 taken at center.
103	1.1	118.2	Thin-bedded, fine-grained, quartzose sandstone with minor silty shale

			interbeds. Unit thickens and coarsens upward.
104	1.4	119.6	Thin-bedded, fine-grained, quartzose sandstone with minor silty shale interbeds. Unit thickens and coarsens upward.
105	.4	120.0	Massive, medium-bedded, very fine- to fine grained micaous sandstone. SAMPLE W-23 taken at base.
106	1.0	121.0	Poorly exposed, thin-bedded, very fine- to fine-grained sandstone. Possibly horizontally laminated. Some silty shale interbeds also present.
107	1.5	122.5	Massive, medium- to thick-bedded, well sorted, fine-grained feldspathic sandstone.
108	1.8	124.3	Thin-bedded, well-sorted, fine-grained feldspathic and micacous sandstone. Very minor shale partings occur throughout. SAMPLE W-24 taken at center.
109	0.6	124.9	Medium- to thick-bedded, well-sorted, medium-grained, lithic? and feldspathic sandstone. Possible horizontal-lamination apparent on some faces.
110	.5	125.5	Interbedded: 1) horizontally laminated, very fine-grained micacous sandstone; and 2) horizontally laminated silty shale. Base of sandstone beds displays load casts.
111	.2	125.7	Horizontally laminated, medium-grained, micaous sandstone. SAMPLE W-25 taken at base.
112	1.3	127.0	Massive, very thick-bedded, well-sorted, fine-grained quartzose sandstone.
113	2.3	129.2	Medium- to thick-bedded, well-sorted medium-grained quartzose sandstone.

			Possible low-angle, planar -tabular cross-stratification present. Few scattered *Skolithos* visible on top of upper bed
114	1.2	130.4	Medium-bedded, fine- to medium-grained, well-sorted quartzose sandstone. top of bed displays purplish stain, few rare Skolithos visible.
115	.6	131.0	Interbedded (40/60): 1) thin-bedded, fine-grained quartzose sandstone; and 2) horizontally laminated silty shale.
116	1.2	132.2	Interbedded (70/30): 1) thin-bedded, fine- to medium-grained quartzose sandstone; and 2) horizontally laminated silty shale. Unit coarsens and thickens upward.
117	1.5	133.7	Poorly exposed, massive, very thick-bedded, medium-grained quartzose sandstone.
118	.7	134.4	Poorly exposed, massive, very thick-bedded, medium-grained quartzose sandstone.
119	1.2	135.6	Interbedded (40/60): 1) medium-bedded, fine- to medium-grained quartzose sandstone; and 2) horizontally laminated shale. Units fines and thins upward.
120	.6	136.2	Massive, medium-bedded, well-sorted quartzose sandstone. Base and top of unit sharp and planar.
121	.4	136.6	Interbedded (20/80): 1) medium-bedded, fine- to medium-grained quartzose sandstone; and 2) horizontally laminated shale. Unit coarsens and thickens upward.
122	3.0	139.6	Covered interval (talus).
123	1.5	141.1	Horizontally laminated shaley siltstone. Minor 1-2 cm thick, hummocky

			stratified, siltstone beds occur throughout.
124	.5	141.6	Thin-bedded, dark gray siltstone with minor interval of horizontally laminated shale present at base. SAMPLE W-27 taken at top.
125	1.5	143.1	Horizontally laminated to thin-bedded, dark gray silty shale. Unit capped by single, thin bed of very fine- to fine-grained sandstone. Units coarsens upward.
126	.3	143.4	Horizontally laminated, dark gray silty shale.
127	1.0	144.4	Horizontally laminated to thin-bedded, dark gray silty shale. Unit capped by single, thin bed of very fine-grained sandstone. Units coarsens upward slightly.
128	.6	145.0	Thin-bedded, siltstone to very-fine grained sandstone. Dewatering structures (flames) disrupting horizontal lamination apparent on some faces. SAMPLE W-28 taken at center.
129	.5	145.5	Horizontally laminated silty shale and thin bedded, siltstone. Unit Coarsens and thickens upward. SAMPLE W-29 taken at top.
130	.4	145.9	Thin-bedded to horizontally laminated siltstone and silty shale. Dewatering structures (flames) disrupting horizontal lamination apparent on some faces. SAMPLE W-30 taken at top.
131	1.5	147.4	Interbedded (60/40): thin-bedded siltstone; and 2) horizontally laminated, very fine-grained micacous sandstone. Unit coarsens upward.
132	1.1	148.5	Interbedded (40/60): thin-bedded siltstone; and 2) horizontally laminated, very fine-grained micacous sandstone. Unit coarsens upward.

133	1.0	149.5	Interbedded (20/80): thin-bedded siltstone; and 2) horizontally laminated, very fine-grained micacous sandstone. Unit coarsens and thickens upward. SAMPLE W-31 taken at top.
134	1.3	151.8	Interbedded (80/20): thin-bedded siltstone; and 2) horizontally laminated, very fine-grained micacous sandstone. Unit fines and thins upward.
135	1.5	153.3	Thin- to medium bedded, siltstone and very fine-grained micaous sandstone. Beds appear to be horizontally laminated internally. Unit fines upward.
136	1.1	154.4	Horizontally laminated silty shale with possible *Planolites*. Unit capped by minor 10 cm thick siltstone bed.
137	.3	154.7	Medium- to thick-bedded, siltstone to very fine-grained sandstone. Unit may be hummocky stratified. Bottom of sandstone displays load casts. SAMPLE W-32 taken at base.
138	1.5	156.2	Thin-bedded siltstone to very fine-grained sandstone. Unit thins and fines upward.
139	1.6	157.8	Horizontally laminated silty shale. Unit coarsens and thickens upward into thin-bedded siltstone.
140	1.5	159.3	Interbedded (30/70): 1) thin-bedded siltstone to very fine-grained sandstone; and 2) horizontally laminated silty shale. Unit fines and thins upward.
141	1.6	160.9	Horizontally laminated silty shale.
142	.4	161.3	Very thin-bedded siltstone.
143	2.1	163.4	Horizontally laminated silty shale. Unit coarsens and thickens upward into

			thin-bedded, very fine-grained sandstone.
144	1.1	164.5	Horizontally laminated silty shale. Unit coarsens and thickens upward into thin-bedded siltstone.
145	4.5	169.0	Poorly exposed, possibly horizontally laminated silty shale. Unit appears to coarsen and thicken upward into thin-bedded siltstone. Float contains *Planolites*.
146	.4	169.4	Massive, thin- to medium bedded, siltstone to very fine-grained sandstone. SAMPLE W-33 taken at top.
147	1.5	170.9	Poorly exposed, thin-bedded, very fine-grained quartzose sandstone with minor interbeds of silty shale. Unit coarsens and thickens upward. SAMPLE W-34 taken near center.
148	5.9	176.8	Covered interval (soil and vegetation).
149	2.5	179.3	Poorly exposed (moss and lichens), very thin- to thin-bedded, fine- to medium-grained, micaous sandstone. Minor shale partings occur in lower part. Unit coarsens and thickens slightly upsection. SAMPLE W-35 taken at top.
150	1.0	180.3	Poorly exposed (moss and lichens), very thin- to thin-bedded, fine- to medium-grained, micaous sandstone. Minor shale partings occur in lower part. Unit coarsens and thickens slightly upsection.
151	.4	180.7	Interbedded (20/80): 1) thin-bedded, fine-grained micaous sandstone; and 2) horizontally laminated silty shale with *Planolites*. Unit coarsens and thickens slightly upward.
152	1.0	181.7	Covered interval (vegetation).

153	.8	182.5	Poorly exposed, interbedded (50/50): 1) thin-bedded, fine-grained micaous sandstone; and 2) horizontally laminated silty shale with *Planolites*. Unit coarsens and thickens slightly upward.
154	.4	182.9	Thin- to medium-bedded, fine- to medium-grained sandstone with minor thin siltstone interbeds. Unit coarsens and thickens upward slightly. SAMPLE W-37 taken at top.
155	1.3	184.2	Horizontally laminated siltstone. unit coarsens and thickens upward into very thin-bedded, very fine- to fine-grained sandstone.
			Base of Nebo Formation
156	1.4	185.6	Thin-bedded, very fine-grained sandstone with minor very thin siltstone interbeds. Sandstone maybe ripple cross-stratified.
157	.3	185.9	Thin-bedded, very fine-grained, micaous sandstone, possibly hummocky stratified.
158	.4	186.3	Poorly exposed, horizontally laminated silty shale and siltstone.
159	1.4	187.7	Thin- to medium-bedded, poorly sorted, fine- to medium-grained sandstone, possibly hummocky stratified. SAMPLE W-37
160	1.5	189.2	Thin- to medium-bedded, very fine-grained sandstone with minor horizontally laminated silty shale interbeds. Sandstone may be hummocky stratified. Unit coarsens and thickens upward slightly.
161	.6	189.8	Thin- to medium-bedded, very fine-grained sandstone with minor horizontally laminated silty shale interbeds. Sandstone may be

			hummocky stratified. Unit coarsens and thickens upward slightly.
162	1.0	190.8	Interbedded (70/30): 1) thin-bedded, fine-grained sandstone; and 2) horizontally laminated silty shale. Unit coarsens and thickness upward.
163	.5	191.3	Medium-bedded, fine- to medium-grained sandstone, possibly hummocky stratified. Base of unit shows load-casts.
164	1.1	192.4	Interbedded (70/30): 1) medium-bedded, medium-grained sandstone; and 2) horizontally laminated silty shale. Unit coarsens and thickens upward. SAMPLE W-40 taken at top.
165	1.0	193.4	medium-bedded, medium-grained, moderately well-sorted sandstone with minor horizontally laminated shale partings.
166	.7	194.1	Massive, medium-bedded, medium-grained sandstone. SAMPLE W-41 taken at center.
167	.3	194.4	Horizontally laminated siltstone. Unit coarsens upward gradually into thin-bedded, fine-grained sandstone.
168	1.2	195.6	Interbedded (60/40): 1) thin- to medium-bedded, well-sorted, medium-grained quartzose sandstone; and 2) horizontally laminated silty shale. Unit coarsens and thickens upward. SAMPLE W-41 taken at top.
169	.3	195.9	Thin-bedded, fine-grained sandstone with minor horizontally laminated siltstone interbeds. Unit fines and thins upward.
170	1.0	196.9	Fine- to medium-grained, medium-bedded sandstone. Unit possibly hummocky stratified with base showing load casts.

171	.3	197.2	Horizontally laminated, very fine-grained sandstone and siltstone.
172	.5	197.7	Medium-bedded, fine-grained, well-sorted quartzose sandstone. Some beds appear to be planar-tabular cross-stratified. Base of unit shows load casts.
173	.9	198.6	Massive, thick-bedded, well-sorted and well indurated quartzose sandstone. Top and base of unit sharp and planar.
174	.5	199.1	Interbedded (50/50): 1) horizontally laminated shaley siltstone; and thin-bedded, fine-grained sandstone. Base of sandstone beds show dewatering marks (dimpled appearance). SAMPLE W-43 taken at base.
175	.9	200.0	Medium- to thick-bedded, well-sorted, fine-grained quartzose sandstone. Some beds appear to be planar-tabular cross-stratified. Base of unit shows load casts.
176	.3	200.3	Interbedded (50/50): 1) horizontally laminated shaley siltstone; and thin-bedded, fine-grained sandstone. Base of sandstone beds show dewatering marks (dimpled appearance).
177	1.6	201.9	Medium-bedded, fine-grained quartzose sandstone.
178	.6	202.5	Interbedded (50/50): 1) horizontally laminated shaley siltstone; and thin-bedded, fine-grained sandstone. Base of sandstone beds show dewatering marks (dimpled appearance).
179	1.2	203.7	Massive, medium-bedded, fine-grained, quartzose sandstone.
180	1.5	205.2	Interbedded (20/80): 1) horizontally laminated shaley siltstone; and thin-bedded, fine-grained sandstone. Unit fines and thins upward.

181	1.5	206.7	Interbedded (30/70): 1) horizontally laminated shaley siltstone; and thin-bedded, fine-grained sandstone. Unit fines and thins upward. SAMPLE W-44 taken at top.
182	.4	207.1	Medium-bedded, well-sorted, fine-grained sandstone. Rare *Skolithos* scattered throughout.
183	.2	207.3	Horizontally laminated, shaley siltstone.
184	.4	207.7	Medium-bedded, well-sorted, fine-grained sandstone. Rare *Skolithos* scattered throughout.
185	.6	208.3	Thin- to medium-bedded, moderately well sorted, fine- to medium-grained quartz sandstone. Base of lower beds show possible *Ruzophycus*.
186	1.2	209.5	Medium-bedded, fine- to medium-grained, quartzose sandstone with minor silty shale partings. Some beds appear to be planar-tabular cross-stratified. SAMPLE W-45 taken at base.
187	1.0	210.5	Medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit lichen covered but some areas appear to be small-scale planar-tabular cross-stratified.
188	.9	211.4	Interbedded (70/30): 1) medium-bedded, fine- to medium-grained quartzose sandstone with abundant *Skolithos;* and 2) horizontally laminated silty shale. Sandstone shows purplish stain. SAMPLE W-46 taken at top.
189	1.3	212.7	Medium-bedded, fine-grained quartzose sandstone with minor (1-2 cm thick) horizontally laminated silty shale interbeds. Sandstone may be horizontally laminated.

190	.6	213.3	Massive, well-sorted and indurated, fine-grained quartzose sandstone.
191	.8	214.1	Poorly exposed (lichens), thin- to medium-bedded, well-sorted, fine-grained sandstone.
192	1.2	215.3	Horizontally laminated siltstone.
193	.6	215.9	Medium-bedded, medium-grained quartzose sandstone with single shale parting. SAMPLE W-47 taken at top.
194	1.5	217.4	Interbedded (70/30): 1) medium-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Unit coarsens and thickens upward slightly. SAMPLE W-48 taken at top.
195	.7	218.1	Interbedded (50/50): 1) medium-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Base of sandstone beds show load casts. Unit fines and thins upward slightly.
196	.4	218.5	Medium- to thick-bedded, medium-grained feldspathic sandstone. top and base of unit sharp and planar.
197	.2	218.7	Interbedded (50/50): 1) medium-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Base of sandstone beds show load casts. Unit fines and thins upward slightly.
198	.6	219.3	Thin- to medium-bedded, moderately well-sorted, fine-grained feldspathic sandstone. Beds pinch and swell laterally, base of some beds shows dewatering marks (dimpled appearance).
199	.4	219.7	Poorly exposed, interbedded (50/50): 1) medium-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Base

			of sandstone beds show load casts. Unit fines and thins upward slightly. SAMPLE W-49 taken at base.
200	1.7	221.4	Thin- to medium-bedded, moderately well-sorted, medium-grained quartzose sandstone. Some beds appear horizontally laminated while others appear medium scale, low-angle planar-tabular cross-stratified.
201	3.0	224.4	Poorly exposed (talus), thin- to medium-bedded, moderately well-sorted, medium-grained quartzose sandstone. SAMPLE w-50 taken at center.
202	1.4	225.8	Medium- to thick bedded, very well-sorted, medium -grained quartzose sandstone. Unit appears to be low-angle planar cross-stratified.
203	.7	226.5	Thin- to medium-bedded, moderately well-sorted, medium-grained feldspathic sandstone with minor shale partings. Some thin sandstone beds appear to be horizontally laminated.
204	.2	226.5	Poorly exposed, horizontally laminated silty shale.
205	.4	226.9	Massive, medium-bedded, medium-grained, feldspathic sandstone. Convolute bedding and load casts apparent.
206	1.5	228.4	Massive, thick-bedded, well-sorted, medium-grained quartzose sandstone.
207	.4	228.8	Massive, medium-bedded, well-sorted, medium-grained quartzose sandstone.
208	.2	230.0	Thin-bedded, fine- to medium-grained feldspathic sandstone with minor shale partings. SAMPLE W-51 taken at top.
209	.5	230.5	Single massive bed of thick-bedded, medium-grained quartzose sandstone.

			Base of unit marked by granule/pebble concentration.
210	.6	231.1	Massive, medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone. Unit thins upward.
211	1.1	232.2	Massive, medium-bedded, well-sorted, medium-grained quartzose sandstone.
212	.6	232.8	Thick-bedded, well-sorted, medium-grained quartzose sandstone with abundant *Skolithos* throughout.
213	.5	233.3	Thick-bedded, well-sorted, medium-grained quartzose sandstone with abundant *Skolithos* throughout.
214	1.1	234.4	Poorly exposed, medium-bedded, moderately well-sorted, medium-grained, feldspathic and quartzose sandstone. Beds pinch and swell laterally.
215	.9	235.3	Poorly exposed, medium-bedded, moderately well-sorted, medium-grained, feldspathic and quartzose sandstone.
216	.6	235.9	Very poorly exposed, medium?-bedded, medium-grained, quartzose sandstone.
			Return to roadcut.
217	4.5	240.4	Poorly exposed, medium- to thick-bedded, fine- to medium-grained, quartzose sandstone. Abundant *Skolithos* throughout some beds. SAMPLE W-53 taken at center.
218	3.0	243.4	Covered interval.
219	1.5	244.9	Poorly exposed, thin- to medium-bedded, fine-grained feldspathic sandstone. Some beds may be small-scale trough cross-stratified or hummocky stratified. Shale partings common throughout.

220	.7	245.6	Massive, thick-bedded, fine- to medium-grained feldspathic sandstone.
221	.6	246.2	Massive, thin- to medium bedded, medium-grained feldspathic sandstone. Beds thin upward.
222	.5	246.7	Poorly exposed, interbedded (20/80): 1) thin-bedded, very fine-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Unit appears to fine and thin upward.
223	1.1	247.8	Poorly exposed, interbedded (40/60): 1) thin-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Unit appears to coarsen and thicken upward.
224	1.0	248.8	Poorly exposed, medium- to thick-bedded, medium-grained feldspathic sandstone. 2-3 cm thick shale horizons mark bed tops.
225	.2	250.0	Poorly exposed, horizontally laminated silty shale with minor very thin interbeds of very fine- to fine-grained sandstone.
226	.5	250.5	Massive, thick-bedded, medium-grained sandstone. Bed geometry suggests slumping or other soft-sediment deformation into underlying fine-grained interval.
227	1.0	251.5	Covered interval (fine grained).
228	7.5	258.2	Massive, thick-bedded, medium-grained sandstone. Bed geometry suggests slumping or other soft-sediment deformation into underlying fine-grained interval.
229	.4	258.6	Poorly exposed, medium-bedded, fine- to medium-grained sandstone, possibly horizontally laminated.

Top of Nebo Formation and Walland section. Chilhowee Group at Chilhowee Mountain continued at Murray Gap locality.

Chilhowee Mountain section continued
(Murray Gap)

230	5.5	264.1	Covered interval (scree).
231	1.5	265.6	Poorly exposed, horizontally laminated siltstone and silty shale.
232	.5	266.1	Thin-bedded, poorly sorted, fine-grained micaous sandstone to silty shale. Base of each bed appears planar, top appears swaley. Unit may be hummocky stratified.SAMPLE MG-1 taken at top.
233	.2	266.3	Horizontally laminated siltstone and silty shale. Float contains *Planolites*.
234	.7	267.0	Thin- to medium-bedded, poorly sorted, fine-grained lithic and micaous sandstone. Unit appears hummocky stratified. SAMPLE MG-2 taken at top.
235	.3	267.3	Horizontally laminated siltstone and silty shale. Float contains *Planolites*.
236	.3	267.6	Thin- to medium-bedded, poorly sorted, fine-grained lithic and micaous sandstone. Unit appears hummocky stratified.
237	.5	268.1	Horizontally laminated siltstone and very fine-grained micaous sandstone. Unit coarsens upward slightly.
238	2.0	270.1	Covered interval (scree).
239	3.0	273.1	Poorly exposed and highly cleaved, horizontally laminated? silty shale.
240	1.5	274.6	Poorly exposed and highly cleaved, horizontally laminated? silty shale.
241	1.5	276.1	Poorly exposed and highly cleaved, horizontally laminated? silty shale. Unit coarsens upward slightly and is capped by single thin bed of very fine grained micaous sandstone.

242	.5	276.6	Covered interval (Foothills Parkway).
243	30.5	307.1	Poorly exposed (scree), dark brown to dark gray, fissile shale. Silty shale horizons obvious as they weather into ledges. Glauconite rich layers occur throughout. SAMPLES MG-3 (254.4), MG-4 (276.9), MG-7 a,b,c (279.1), and MG-8 (281.9) taken by saw and resin.
244	4.5	311.6	Horizontally laminated siltstone and thin-bedded, very fine-grained micaous sandstone. Sandstone beds are hummocky stratified. SAMPLE MG-9 taken at base.
245	4.8	316.4	Interbedded (80/20): 1) thin-bedded, very fine-grained micaous sandstone; and 2) horizontally laminated silty shale. Sandstone is hummocky stratified. Unit coarsens and thicken upward slightly.
246	2.7	319.1	Horizontally laminated, greenish gray siltstone and silty shale. Minor thin beds of very fine-grained sandstone occur near top of unit. Sandstone appears horizontally laminated.
247	4.5	324.6	Interbedded (70/30): 1) thin-bedded, very fine-grained micaous sandstone; and 2) horizontally laminated silty shale. Sandstone is hummocky stratified. Unit coarsens and thicken upward slightly. SAMPLE MG-10 taken at center.
248	9.0	333.6	Interbedded (40/60): 1) thin-bedded, very fine-grained micaous sandstone; and 2) horizontally laminated silty shale. Unit exposed as saprolite. Unit coarsens and thicken upward slightly.
249	4.5	338.1	Covered interval.

250	1.7	339.8	Poorly exposed, massive, medium- to thick-bedded, fine- to medium-grained quartzose sandstone.
251	.1	339.9	Thin-bedded, medium-grained, quartzose sandstone. Unit appears to be low-angle planar-tabular cross-stratified. Bed surface shows assymetric ripples. SAMPLE MG-11 taken at top.
252	1.0	340.9	Massive, very thick-bedded, medium-grained quartzose sandstone.
253	.8	341.7	Massive, very thick-bedded, medium-grained quartzose sandstone.
254	7.8	349.5	Covered interval.
255	1.5	351.0	Massive, medium-bedded, fine-grained quartzose sandstone. SAMPLE MG-12 taken at top.
256	.4	351.4	Thin- to medium-bedded, fine-grained quartzose sandstone. Unit appears to be low-angle planar-tabular cross-stratified.
257	2.8	354.2	Massive, thin- to medium-bedded, fine-grained quartzose sandstone. SAMPLE MG-13 taken at center.
258	3.0	357.2	Massive, thin- to medium-bedded, fine-grained quartzose sandstone.
259	2.8	360.0	Massive, thin- to medium-bedded, fine-grained quartzose sandstone.
260	18.0	378.0	Thick-bedded, medium-grained quartzose sandstone. Unit is large-scale, high-angle planar-tabular cross-stratified. SAMPLE MG-14 taken at base.

UNIT	THICK. (m)	CUMM. THICK. (m)	DESCRIPTION
Section through Erwin Formation along Interstate 40 six miles south of Newport, Tennessee (I-40).			Base of section at lower contact with Hampton Formation.
1	1.0	1.0	Massive, thin- to medium-bedded, fine- to medium grained quartzose sandstone.
2	1.5	2.5	Massive, thick- to very thick-bedded, well sorted, fine-grained quartzose sandstone.
3	.5	3.0	Massive, thick-bedded, well sorted, fine-grained quartzose sandstone.
4	1.1	4.1	Massive, thin- to thick-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally.
5	1.1	5.2	Massive, thin-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* scattered throughout.
6	1.5	6.7	Massive, thin- to thick-bedded, fine- to medium-grained quartzose sandstone. Thicker units may have clay drapes.
7	.9	7.6	Massive, thin-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally. *Skolithos* concentrated near top.
8	1.1	8.7	Massive, medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* scattered throughout.
9	1.4	10.1	Massive, thin-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* scattered throughout.
10	.9	11.0	Very thin- to thin-bedded, well sorted, fine-grained quartzose sandstone with

			occasional thin, horizontally laminated shale interbeds. Sandstone beds pinch and swell laterally.
11	2.3	13.3	Massive, medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* scattered throughout.
12	2.9	16.2	Massive, medium-bedded, well-sorted, fine-grained quartzose and feldspathic sandstone. Unit pinches and swells laterally. Rare *Skolithos* scattered throughout. SAMPLE I-40-1 taken at top.
13	1.2	17.4	Massive, medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* scattered throughout. Purple stain common.
14	1.5	18.9	Massive, thick-bedded, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* concentrated near top of each bed. Purple stain common.
15	1.0	19.9	Massive, thick-bedded, fine-grained quartzose sandstone. Unit pinches and swells laterally. Rare *Skolithos* concentrated near top of each bed. Purple stain common.
16	1.0	20.9	Massive, thick-bedded, fine-grained quartzose sandstone. Base and top of unit are planar. Rare *Skolithos* concentrated near top of each bed. Purple stain common.
17	1.2	22.1	Interbedded (60/40): 1) thin-bedded, well sorted, fine-grained quartzose sandstone; and 2) friable, horizontally laminated silty shale to very fine-grained sandstone. Fine-grained sandstone beds appear to have scoured bases. Rare *Skolithos* scattered throughout.

18	1.2	23.3	Massive, thick-bedded, fine-grained quartzose sandstone. Base and top of unit are planar. Large-diameter Skolithos concentrated near top of each bed. Purple stain common.
19	1.5	24.8	Poorly exposed (talus), Massive, thick-bedded, fine-grained quartzose sandstone. Rare *Skolithos* concentrated near top of each bed. Purple stain common. Unit maybe small-scale trough cross-stratified.
20	1.5	26.3	Covered interval (talus slope).
21	1.5	27.8	Poorly exposed (lichens), thin- to medium-bedded, fine-grained quartzose sandstone. Unit thins upward. Beds have swaley tops.
22	2.9	30.7	Massive, thick-bedded, fine-grained quartzose sandstone. *Skolithos* common throughout but form true "pipe rock" along a single 10 cm thick horizon near middle of unit. Purple stain common.
23	1.0	31.7	Massive, thin- to medium-bedded, fine-grained feldspathic sandstone. Unit thins upward slightly. Beds pinch and swell. *Skolithos* less dense but still common.
24	3.0	34.7	Massive, thick-bedded, fine-grained feldspathic sandstone. Rare *Skolithos* concentrated near top of each bed. Purple stain common. Beds have swaley bases and tops.
25	1.9	36.6	Massive, thick-bedded, fine-grained quartzose sandstone. *Skolithos* concentrated near top of each bed. Purple stain common. Beds pinch and swell laterally.
26	2.6	39.2	Massive, medium-bedded, fine-grained quartzose sandstone. *Skolithos* concentrated near top of each bed.

			Purple stain common. Top and base of each bed planar.
27	1.0	40.2	Massive, thick- to very-thick bedded, fine-grained quartzose sandstone. *Skolithos* abundant near top of each bed. Purple stain common. Beds pinch and swell laterally.
28	1.0	41.2	Poorly exposed, massive, thin- to medium-bedded, fine-grained quartzose sandstone. *Skolithos* concentrated near top of each bed. Top and base of each bed planar.
29	1.0	42.2	Massive, medium-bedded, fine-grained quartzose sandstone. *Skolithos* concentrated near top of each bed and form true "piperock" at top.
30	2.2	44.4	Massive, medium- to very thick-bedded, highly bioturbated (*Skolithos*) fine-grained quartzose sandstone. "Piperock" common throughout.
31	.8	45.2	Massive, thin- to medium-bedded, fine-grained quartzose sandstone with occasional shale partings. Sandstone beds pinch and swell laterally.
32	.4	45.6	Massive, thin- to medium-bedded, fine-grained quartzose sandstone with occasional shale partings. Sandstone beds pinch and swell laterally.
33	3.0	48.6	Massive, thick- to very-thick bedded, fine-grained quartzose sandstone. *Skolithos* abundant near top of each bed. Tops of many beds marked by shale partings.
34	1.6	50.2	Massive, medium-bedded, well-sorted, medium-grained quartzose sandstone. *Skolithos* concentrated near top of each bed.
35	1.0	51.2	Covered interval.

36	.5	51.7	Massive, medium-bedded, well-sorted, fine-grained quartzose sandstone with *Skolithos* common throughout.
37	1.0	52.7	Covered interval.
38	.4	53.1	Interbedded (50/50): 1) thin-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. SAMPLE I-40-3 taken near center.
39	2.0	55.1	Covered interval (fine grained).
40	.5	55.6	Medium-bedded, fine- to medium-grained feldspathic sandstone. *Skolithos* form "piperock".
41	1.4	57.0	Interbedded (60/40): 1) thin-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale.
42	.7	57.7	Massive, poorly sorted, fine-grained micaous sandstone.
43	1.4	59.1	Thin- to medium-bedded, very fine- to fine-grained feldspathic sandstone. Unit appears to be horizontally laminated. Shale partings occur throughout.
44	1.2	60.3	Medium-bedded, very fine- to fine-grained feldspathic sandstone. Unit appears to be horizontally laminated. Shale partings occur throughout.
45	2.0	62.3	Covered interval (fine grained).
46	.7	63.0	Thin- to medium-bedded, very fine- to fine-grained feldspathic sandstone. Unit appears to be horizontally laminated. Shale partings occur throughout.
47	3.0	66.0	Covered interval (fine grained).
48	1.5	67.5	Interbedded (60/40): 1) thin-bedded, fine- to medium-grained feldspathic

			sandstone; and 2) horizontally laminated silty shale.
49	.8	68.3	Horizontally laminated, very fine-grained micaous feldspathic sandstone.
50	1.4	69.7	Interbedded (60/40): 1) thin-bedded, fine- to medium-grained feldspathic sandstone; and 2) horizontally laminated silty shale. Sandstone appears hummocky stratified.
51	1.0	70.7	Poorly exposed, horizontally laminated?, very fine-grained micaous feldspathic sandstone.
52	3.0	73.7	Covered interval (talus).
53	.8	74.5	Poorly exposed, horizontally laminated?, very fine-grained micaous feldspathic sandstone.
54	1.0	75.5	Poorly exposed, horizontally laminated, very fine-grained micaous feldspathic sandstone.
55	.9	76.4	Massive, thick-bedded, well-sorted, medium-grained quartzose sandstone.
56	1.5	77.9	Covered interval (fine grained).
57	2.3	80.2	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone. Coarsens upward slightly.
58	.4	80.6	Medium-bedded, well-sorted, fine-grained quartz sandstone. Abundant *Skolithos* throughout.
59	.4	81.0	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
60	.3	81.3	Medium-bedded, fine-grained quartzose sandstone. Single bed form channel-like feature. Unit appears high-angle planar-tabular cross-stratified.

61	.4	81.7	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
62	.4	82.1	Medium-bedded, fine-grained quartzose sandstone. Single bed form channel-like feature. Unit appears high-angle planar-tabular cross-stratified.
63	.2	82.3	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
64	.8	83.1	Massive, thick-bedded, well-sorted, fine-grained quartzose sandstone. Base of units shows load casts.
65	.2	83.3	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
66	1.0	84.3	Massive, medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit appearance vaguely suggestive of medium-scale trough cross-stratification. Rare *Skolithos* scattered throughout.
67	.9	85.2	Massive, medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit appearance vaguely suggestive of medium-scale trough cross-stratification. *Skolithos* abundant throughout. Purple stain common.
68	2.5	87.7	Covered interval (talus).
69	1.1	88.8	Massive, medium-bedded, well-sorted, fine-grained feldspathic and quartzose sandstone. Unit appearance vaguely suggestive of medium-scale trough cross-stratification. *Skolithos* abundant throughout. Purple stain common.
70	.6	89.4	Medium-bedded, well-sorted, fine-grained quartzose sandstone. Unit

			maybe low-angle planar-tabular cross-stratified. Beds pinch and swell laterally.
71	1.5	90.9	Medium- to thick-bedded, well-sorted, very fine- to fine grained quartzose sandstone. Unit appears to be large-scale planar-tabular cross-stratified and is similar in appearance of tidal bundles observed (with S.G. Driese) within Clinch Sandstone (Silurian) at Thorn Hill, Tn.
72	4.0	94.9	Massive, thick-bedded, well-sorted, very fine- to fine grained quartzose sandstone.
73	2.0	96.9	Interbedded (60/40): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Coarser units appear hummocky cross-stratified. Unit coarsens and thickens upward slightly.
74	.5	97.4	Thin-bedded siltstone to very fine-grained sandstone. Coarser units appear hummocky cross-stratified. Base and tops of units swaley in appearance.
75	1.2	98.6	Interbedded (60/40): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Coarser units appear hummocky cross-stratified. Unit coarsens and thickens upward slightly.
76	.6	99.2	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
77	1.5	100.7	Interbedded (40/60): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Coarser units appear hummocky cross-stratified. Unit coarsens and thickens upward slightly.

78	1.5	102.2	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
79	1.1	103.3	Massive, thick-bedded, poorly sorted very fine- to fine-grained micaous quartzose sandstone. Unit has swaley top.
80	1.5	104.8	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
81	.9	105.7	Interbedded (30/70): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally.
82	1.0	106.7	Massive, thick-bedded, poorly sorted very fine- to fine-grained feldspathic and quartzose sandstone. Unit has swaley top.
83	.6	107.3	Horizontally laminated silty shale.
84	2.8	110.1	Massive, thick- to very thick-bedded, poorly sorted, very fine- to fine-grained, feldspathic and quartzose sandstone.
85	1.0	111.1	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
86	2.5	113.6	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone. Base marked by shale parting.
87	1.2	114.8	Medium-bedded, well-sorted, fine-grained, quartzose sandstone. *Skolithos* abundant throughout. Lower portion of unit appears horizontally laminated.

88	.6	115.4	Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone.
89	.6	116.0	Medium-bedded, well-sorted, fine-grained, quartzose sandstone. *Skolithos* abundant throughout.
90	1.5	117.5	Very poorly exposed. Horizontally laminated, poor sorted, Very fine- to fine-grained feldspathic sandstone. Float contains *Planolites* .
91	1.5	119.0	Thick-bedded, well-sorted, fine-grained, quartzose sandstone. *Skolithos* abundant throughout and form "piperock" near top. Purple stain common throughout. Shale partings mark bedding planes.
92	1.5	120.5	Medium-bedded, well-sorted, fine-grained, quartzose sandstone. *Skolithos* abundant throughout.
93	8.3	128.3	Interbedded (30/70): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. Coarser units probably hummocky stratified. Reminiscent of Murray Shale at Murray Gap.
94	3.0	131.3	Massive, thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally.
95	1.0	132.3	Thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. Coarser units probably hummocky stratified. Finer grained units appear horizontally laminated.
96	1.1	133.4	Massive, thin-bedded, very fine-grained feldspathic sandstone. Unit

			coarsens and thickens upward slightly. Beds pinch and swell laterally.
97	1.2	134.6	Poorly exposed, interbedded (30/70): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally.
98	3.5	138.1	Poorly exposed, interbedded (20/80): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally.
99	2.5	140.6	Poorly exposed, thin- to medium-bedded, moderately well sorted, fine-grained feldspathic and quartzose sandstone. Beds have swaley bases and tops.
100	24.0	164.6	Covered interval (talus slope).
101	2.0	166.6	Poorly exposed, thin- to medium-bedded, moderately well sorted, fine-grained feldspathic and quartzose sandstone. *Skolithos* and glauconite scattered throughout. Beds have swaley bases and tops. Unit appears horizontally laminated in some places.
102	1.7	168.3	Thin- to medium-bedded, moderately well sorted, fine-grained feldspathic and quartzose sandstone. Beds have swaley bases and tops. Rare *Skolithos* scattered throughout. Some units appear low-angle planar-tabular cross-stratified.
103	1.5	169.8	Massive, medium-bedded, moderately well sorted, fine-grained feldspathic and quartzose sandstone.
104	.8	170.6	Massive, medium-bedded, moderately well sorted, fine-grained feldspathic and quartzose sandstone. Glauconite scattered throughout.

105	1.5	172.1	Massive, medium-bedded, moderately well sorted, medium-grained feldspathic and quartzose sandstone. Lower beds pinch out laterally to form channel-like geometry.
106	3.1	175.2	Massive, medium-bedded, moderately well sorted, fine-grained feldspathic and quartzose sandstone. Glauconite scattered throughout. Some beds appear hummocky stratified or small-scale trough cross-stratified similar to units at Pilot Mountain.
107	.8	176.0	Poorly exposed, interbedded (20/80): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. Coarser units may be hummocky stratified.
108	1.5	177.5	Thin- to thick-bedded, moderately well-sorted, fine- to medium-grained quartzose (minor feldspar) sandstone. Unit thickens upward. Lower beds appear hummocky stratified.
109	1.0	178.5	Thin-bedded, fine-grained feldspathic sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. Rare *Skolithos* scattered throughout. Purple stain common throughout.
110	1.2	179.7	Thin-bedded, fine-grained feldspathic sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. *Skolithos* dense near bed tops and forms "piperock" near unit top. Purple stain common throughout.
111	2.2	191.9	Thin-bedded, fine- to medium-grained, quartzose and feldspathic sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. Rare *Skolithos* scattered

			throughout. Purple stain common throughout.
112	.7	192.6	Interbedded (30/70): 1) horizontally laminated silty shale; and 2) thin-bedded siltstone to very fine-grained sandstone. Unit coarsens and thickens upward slightly. Beds pinch and swell laterally. Coarser units may be hummocky stratified.
113	2.5	195.1	Massive, medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone.
114	1.0	196.1	Poorly exposed, interbedded (30/70?): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone.
115	2.8	198.9	Massive, medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone.
116	3.0	201.9	Massive, medium-bedded, fine- to medium-grained, quartzose and feldspathic sandstone. Glauconite scattered throughout.
117	.4	202.3	Massive, medium-bedded, moderately well-sorted, medium-grained quartzose and feldspathic sandstone.
118	.6	202.9	Covered interval (fine-grained).
119	1.1	204.0	Massive, medium-bedded, well-sorted, medium-grained, quartzose sandstone. *Skolithos* scattered throughout.
120	.7	204.7	Thin- to medium-bedded, well-sorted, medium-grained, quartzose sandstone.*Skolithos* scattered throughout. Unit capped by 2-4 cm thick horizon of very coarse-grained quartz sandstone to granule conglomerate.
121	1.3	206.0	Medium-bedded, well-sorted, medium-grained quartzose sandstone. Unit is

			large-scale planar-tabular cross-stratified. Unit capped by 8-20 cm thick horizon of very coarse-grained quartz sandstone to granule conglomerate. SAMPLE I-40-6 taken at top.
122	1.1	207.1	Massive, thin- to medium-bedded?, well-sorted, fine- to medium-grained quartzose sandstone.
123	1.2	208.3	Covered interval (fine grained and talus slope).
124	.6	208.9	Massive, single bed of fine-grained quartzose sandstone.
125	2.2	211.1	Interbedded (40/60): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone. Unit fines and thins upward.
126	1.5	212.6	Poorly exposed, interbedded (50/50): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone. Unit fines and thins upward.
127	.8	213.4	Massive, single bed of fine-grained quartzose sandstone. SAMPLE I-40-7 taken at top.
128	1.0	214.4	Interbedded (50/50): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone. Unit fines and thins upward.
129	1.1	215.5	Massive, medium- to thick-bedded, fine-grained quartzose sandstone. Glauconite scattered throughout. SAMPLE I-40-9 taken at top.
130	.7	216.2	Interbedded (50/50): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone. Unit fines and thins upward.

131	1.5	217.7	Massive, medium- to thick-bedded, fine-grained quartzose sandstone. Glauconite scattered throughout.
132	.3	218.0	Poorly exposed horizontally laminated silty shale.
133	.7	218.7	Horizontally laminated, very fine-grained sandstone.
134	.6	219.3	Massive, thin- to medium-bedded, fine-grained quartzose sandstone. Glauconite scattered throughout.
135	.7	220.0	Horizontally laminated, very fine-grained sandstone.
136	1.0	221.0	Interbedded (50/50): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone. Unit fines and thins upward.
137	.9	221.9	Horizontally laminated, fine-grained sandstone.
			Base? of Helenmode Formation.
138	4.5	225.4	Poorly exposed and deeply weathered, interbedded (60/40): 1) horizontally laminated silty shale; and 2) thin-bedded, very fine-grained sandstone. Unit fines and thins upward. Coarser units appear horizontally laminated.

UNIT	THICK. (m)	CUMM. THICK. (m)	DESCRIPTION
English Mountain Section			Cochran Formation (partial section uppermost Cochran only).
1	3.9	3.9	Thick-bedded, moderately well-sorted, very coarse-grained granule - pebble, feldspathic sandstone. Some beds are large-scale trough cross-stratified, others appear horizontally laminated.
2	2.0	5.9	Medium- to thick-bedded, moderately well-sorted, coarse- to very coarse-grained, feldspathic and lithic sandstone. Some beds are medium- to large-scale trough cross-stratified, others appear horizontally laminated. Unit coarsens and thickens upward but is capped with 4-5 cm thick silty shale horizon.
3	1.7	7.6	Poorly exposed, massive, medium- to thick-bedded, feldspathic and lithic sandstone.
4	1.5	9.1	Covered interval (talus).
5	.8	9.9	Massive, thick-bedded, moderately well-sorted, coarse-grained granule - pebble, feldspathic and lithic sandstone. Upper portion possibly medium-scale trough cross-stratified.
6	1.5	11.4	Massive, thick-bedded, moderately well-sorted, coarse-grained granule - pebble, feldspathic and lithic sandstone.
7	1.5	12.9	Poorly exposed, interbedded (70/30): 1) thin-bedded, medium-grained feldspathic sandstone; and 2) very poorly exposed silty shale.
8	1.5	14.4	Covered interval (fine grained?, talus covered).
9	.6	15.0	Massive, thick-bedded, moderately well sorted, medium-grained feldspathic and quartzose sandstone.

10	1.6	16.6	Covered interval (colluvium).
11	1.5	17.1	Thick-bedded, moderately well sorted, medium-grained quartzose sandstone. Unit appears to be horizontally laminated.
12	3.0	20.1	Poorly exposed (weathered), thick bedded, moderately well sorted, medium-grained feldspathic and lithic sandstone. Unit appears to be medium-scaled trough cross-stratified.
13	2.5	22.6	Poorly exposed (weathered), thick bedded, moderately well sorted, medium-grained feldspathic and lithic sandstone. Unit appears to be medium-scaled trough cross-stratified.
14	3.0	25.6	Massive, thick-bedded, medium-grained quartzose sandstone.
15	1.3	26.9	Covered interval (talus).
16	5.0	31.9	Medium- to thick-bedded, poorly sorted, coarse-grained granular to pebbly sandstone. Unit is medium- to large-scale trough cross-stratified. Unit thickens upward.
			End of section at top of The Pinnacle. Upper contact with Nichols Formation not exposed.

UNIT	THICK. (m)	CUMM. THICK. (m)	DESCRIPTION
Hampton Section (Doe River Gorge)			Cochran Formation (partial section uppermost Cochran only).
BASEMENT			Nonconformity with granitic and gneissic rock. SAMPLES DR-B (gneiss) and DR-1 (granite) taken at 10 m below and at contact, respectively.
1	3.0	3.0	Massive, medium- to thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic and lithic sandstone to granule - pebble conglomerate. Beds pinch and swell laterally. SAMPLE DR-2 taken at top.
2	3.0	6.0	Massive, medium- to thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic and lithic sandstone to granule - pebble conglomerate. Beds pinch and swell laterally.
3	2.5	8.5	Poorly exposed, medium-bedded, moderately well sorted, very coarse-grained to granular feldspathic sandstone.
4	2.3	10.8	Massive, medium- to thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic and lithic sandstone to granule - pebble conglomerate. Beds pinch and swell laterally. Unit thins upward slightly.
5	34.5	45.3	Covered interval.
6	1.0	46.3	Massive, thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic sandstone. Beds pinch and swell laterally. Unit may be medium-scaled trough cross-stratified. SAMPLE DR-3 taken at base.
7	1.5	47.8	Massive, medium- to thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic sandstone. Beds

			pinch and swell laterally. Unit may be medium-scaled trough cross-stratified.
8	1.5	49.3	Poorly exposed, thick-bedded, coarse- to very coarse-grained and pebbley (quartz), feldspathic sandstone. Beds pinch and swell laterally. Unit may be medium-scaled trough cross-stratified.
9	5.2	54.5	Thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic sandstone. Beds pinch and swell laterally. Unit may be medium-scaled trough cross-stratified. Unit fines and thins upward slightly.
10	6.0	60.5	Thick-bedded, coarse- to very coarse-grained and pebbley, feldspathic sandstone. Beds pinch and swell laterally. Unit may be medium-scaled trough cross-stratified. Unit fines and thins upward slightly. SAMPLE DR-4 taken at base.
11	3.0	63.5	Massive, thick-bedded, coarse- to very coarse-grained, feldspathic and lithic sandstone. Beds pinch and swell laterally. SAMPLE DR-5 taken 2.7 m above base of unit (63.2 m above base of section).
12	1.5	65.0	Massive, thick-bedded, coarse- to very coarse-grained, feldspathic and lithic sandstone. Beds pinch and swell laterally. Unit may be medium-scaled trough cross-stratified.
13	2.3	67.3	Poorly exposed, interbedded (40/60): 1) thick-bedded, coarse- to very coarse-grained, feldspathic sandstone; and 2) very fine- to fine-grained, feldspathic sandstone. Beds pinch and swell laterally. Unit fines and thins upward slightly.
14	13.5	80.8	Covered interval.

15	2.0	82.8	Massive, medium- to thick-bedded, moderately well sorted, medium-grained feldspathic sandstone. Beds pinch and swell laterally.
16	3.3	86.1	Massive, medium- to thick-bedded, moderately well sorted, medium-grained feldspathic sandstone. SAMPLE DR-6 taken 3.0 m above base of unit (85.8 m above base of section).
17	3.0	89.1	Massive, medium- to thick-bedded, moderately well sorted, medium-grained feldspathic sandstone.
18	3.0	92.1	Medium- to thick-bedded, coarse- to very coarse-grained to granular, feldspathic sandstone. Beds pinch and swell laterally. Unit fines and thins upward slightly. SAMPLE DR-7 taken at top.
19	4.5	96.6	Medium- to thick-bedded, coarse- to very coarse-grained to granular, feldspathic sandstone. Beds pinch and swell laterally. Unit fines and thins upward slightly.
20	4.4	101.0	Massive, thin- to medium-bedded, coarse- to very coarse-grained to granular, feldspathic sandstone. Beds pinch and swell laterally. Unit fines and thins upward slightly. Shale partings common in upper portion.
21	1.5	102.5	Interbedded (20/80): 1) thin-bedded, fine-grained feldspathic sandstone with shale stringers; and 2) medium-bedded, very coarse to granular feldspathic sandstone. Coarse units appear to be planar-tabular cross-stratified. Unit fines and thins upward. SAMPLE DR-8 taken 0.3 m above base of unit (101.3 m above base of section).
22	1.7	104.2	Interbedded (40/60): 1) thin-bedded, fine-grained feldspathic sandstone with shale stringers; and 2) medium-bedded,

			very coarse to granular feldspathic sandstone. Coarse units appear to be planar-tabular cross-stratified. Unit fines and thins upward.
23	4.5	108.7	Interbedded (50/50): 1) thin-bedded, fine-grained feldspathic sandstone with shale stringers; and 2) medium-bedded, very coarse to granular feldspathic sandstone. Coarse units appear to be planar-tabular cross-stratified. Unit fines and thins upward.
24	.8	109.5	Poorly exposed, thin-bedded, fine-grained feldspathic sandstone with shale stringers.
25	2.6	112.1	Interbedded (20/80): 1) thin-bedded, fine-grained feldspathic sandstone with shale stringers; and 2) medium-bedded, very coarse to granular feldspathic sandstone. Coarse units appear to be planar-tabular cross-stratified. Unit coarsens and thickens upward.
26	1.5	113.6	Interbedded (10/90): 1) thin-bedded, fine-grained feldspathic sandstone with shale stringers; and 2) medium-bedded, very coarse to granular feldspathic sandstone. Unit coarsens and thickens upward. SAMPLE DR-9 taken at top.
27	3.2	116.8	Massive, medium- to thick-bedded, coarse-grained to granular, feldspathic sandstone. Base of unit marked by pebble lense.
28	6.5	123.3	Interbedded (30/70): 1) thin-bedded, horizontally laminated, very fine- to fine-grained, feldspathic sandstone to silty shale; and 2) massive, medium-bedded, well-sorted, medium-grained, feldspathic and quartzose sandstone. SAMPLE DR-10 taken 5.7 m above base of unit (122.5 m above base of section).
29	1.5	124.8	Medium-bedded, well-sorted, medium- to coarse-grained, quartzose sandstone.

			Most beds appear medium-scaled, trough cross-stratified.
30	1.5	126.3	Poorly exposed, thin- to medium-bedded, well-sorted, medium-grained quartzose sandstone.
31	1.5	127.8	Thick-bedded, Medium- to coarse-grained, quartzose sandstone. Unit is large-scale planar-tabular cross-stratified similar to Hesse Formation at Look Rock.
32	1.1	128.9	Thick-bedded, medium-grained, quartzose sandstone. Unit is small-scale trough cross-stratified.
33	1.3	130.2	Medium- to thick-bedded, medium-grained, quartzose sandstone. Unit is small-scale trough cross-stratified.
34	1.5	131.7	Poorly exposed, medium- to thick-bedded, medium-grained, quartzose sandstone. Unit appears to be small-scale trough cross-stratified.
35	4.5	136.2	Medium- to thick-bedded, well-sorted, medium-grained, quartzose sandstone. Unit is small-scaled trough cross-stratified. beds pinch and swell laterally and are capped by 5-6 cm silty shale horizons.
36	2.6	138.8	Medium- to thick-bedded, well-sorted, medium-grained, quartzose sandstone. Unit is small-scaled trough cross-stratified. beds pinch and swell laterally and are capped by 5-6 cm silty shale horizons.
37	2.2	141.0	Medium- to thick-bedded, well-sorted, medium-grained, quartzose sandstone. Unit is small-scaled trough cross-stratified. beds pinch and swell laterally and are capped by 5-6 cm silty shale horizons.
38	3.0	144.0	Massive, medium- to thick-bedded, well-sorted, medium-grained,

			quartzose sandstone. Beds pinch and swell laterally.
39	1.5	145.5	Massive, medium- to thick-bedded, well-sorted, medium-grained, quartzose sandstone. Beds pinch and swell laterally. SAMPLE DR- 12 taken at base.
40	1.5	147.0	Massive, thick-bedded, very coarse-grained to pebbly feldspathic sandstone.
41	4.5	151.5	Massive, interbedded (50/50): 1) thin- to medium-bedded, well-sorted, medium-grained quartzose sandstone; and 2) medium- to thick-bedded, coarse-grained feldspathic sandstone. Unit fines and thins- upward slightly.
42	1.5	153.0	Medium-bedded, medium- to coarse-grained and granular feldspathic sandstone. Unit fines and thins upward slightly. SAMPLE DR-13 taken at top.
43	2.1	155.1	Interbedded (80-20): 1) medium-bedded, medium- to coarse-grained and granular feldspathic sandstone; 2) and horizontally laminated, fine-grained feldspathic sandstone to silty shale. Unit thins and fines upward slightly.
44	6.0	161.1	Covered interval (fine grained).
45	.7	161.8	Poorly exposed, medium-bedded?, medium- to coarse-grained, feldspathic sandstone.
46	1.5	163.3	Covered interval.
47	.5	163.8	Poorly exposed, medium-bedded?, medium- to coarse-grained, feldspathic sandstone. SAMPLE DR-13B taken at top.
48	12.0	173.8	Covered interval.

49	2.6	176.4	Massive, medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. SAMPLE DR-13C taken at base.
50	1.2	177.6	Massive, medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone.
51	1.5	179.1	Massive, thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone.
52	1.4	180.5	Massive, thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. unit fines upward slightly. SAMPLE DR-14 taken at base.
53	1.2	181.7	Medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. Unit appears to be medium-scaled trough cross-stratified. Base of unit marked by thin silty shale parting.
54	3.5	185.2	Medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. Unit appears to be medium-scaled trough cross-stratified. Base of unit marked by thin silty shale parting.
55	3.3	188.5	Medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. Unit appears to be medium-scaled trough cross-stratified. Base of unit marked by thin silty shale parting. SAMPLE DR-14B taken at top.
56	1.5	190.0	Massive, medium- to thick-bedded, poorly sorted, medium- to coarse-grained, feldspathic and lithic sandstone.

57	3.0	193.0	Medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. Unit appears to be medium-scaled trough cross-stratified.
58	6.0	199.0	Massive, medium- to thick-bedded, moderately well sorted, coarse to very coarse-grained feldspathic and lithic sandstone. Some granulae layers distributed throughout. SAMPLE DR-15 taken at top.
59	3.3	202.3	Interbedded (30/70): 1) massive, to medium-bedded, granule-pebble conglomerate; and 2) thin- to medium-bedded, moderately well-sorted, feldspathic and lithic sandstone. Sandstone beds may be small-scale trough cross-stratified.
60	2.1	204.4	Massive, medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone.
61	3.1	207.5	Massive, medium- to thick-bedded, poorly sorted, very coarse-grained to granular feldspathic and lithic sandstone. Base marked by 3-5 cm thick silty shale horizon.
62	1.5	209.0	Poorly exposed and deformed (fold-axis), thick-bedded, very coarse-grained to granular, feldspathic and lithic sandstone. SAMPLE DR-15B taken at top.
63	3.4	212.4	Thick-bedded, very coarse-grained to granular, feldspathic and lithic sandstone. Medium-scaled trough cross-stratified.
64	.7	213.1	Interbedded (50/50): 1) medium-bedded, medium- to coarse-grained and granular feldspathic and lithic sandstone; 2) and horizontally laminated, fine-grained feldspathic sandstone to silty shale. Unit thins and

			fines upward slightly. Coarse-grained beds may be medium-scaled trough cross-stratified.
65	1.5	214.6	Massive, thick-bedded, well-sorted, medium-grained feldspathic and lithic sandstone.
66	4.2	218.8	Interbedded (80/20): 1) medium-bedded, medium- to coarse-grained feldspathic and lithic sandstone; 2) and horizontally laminated, fine-grained feldspathic sandstone to silty shale. Unit coarsens and thickens upward slightly. Coarser grained beds may be small-scaled trough cross-stratified. SAMPLE DR-16 taken 2.9 m above base of unit (217.5 m above base of section).
67	3.0	221.8	Medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone. Unit is small-scaled trough cross-stratified or hummocky stratified.
68	3.0	224.8	Medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone. Unit is small-scaled trough cross-stratified or hummocky stratified. Base of unit marked by horizontally laminated fine-grained sandstone layer 10 cm thick.
69	4.1	228.9	Medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone. Unit is small-scaled trough cross-stratified. Base of unit marked by horizontally laminated fine-grained sandstone layer 10 cm thick.
70	4.6	233.5	Poorly exposed, medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone. SAMPLE DR-17 taken 3.1 m above base of unit (232 m above base of section).
71	4.4	237.9	Medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone.

			Unit is small-scaled trough cross-stratified.
72	1.5	239.4	Massive, medium- to thick-bedded, well-sorted, medium-grained quartzose sandstone.
73	.7	240.1	Covered interval.
74	3.0	243.1	Massive, thick-bedded, poorly sorted, very-coarse-grained to granular, feldspathic sandstone.
75	1.6	244.7	Massive, thick-bedded, well-sorted, medium-grained, quartzose sandstone. SAMPLE DR-17B taken at base.
76	2.5	247.2	Poorly exposed, massive, medium- to coarse-grained quartzose sandstone.
77	.6	247.8	Covered interval.
78	3.1	250.9	Massive, thick-bedded, well-sorted, fine- to medium- grained, quartzose sandstone.
79	2.1	253.0	Massive, medium- to thick-bedded, well-sorted, fine- to medium-grained quartzose sandstone. SAMPLE DR-18 taken 1 m above base of unit (251.9 m above base of section).
80	2.7	255.7	Covered interval.
81	.1	255.8	Poorly exposed, medium- to coarse-grained quartzose sandstone.
			Cross covered interval. I am interpreting section as folded and quartzite at tunnel as repeated section of units 76-79. Section then continues at top of quartzose sandstone exposed northeast of tunnel. Based on similar folds seen previously, drastic dip change, and similarity of quartzose sandstone units at both horizons.
82	22.5	278.3	Covered interval.

83	2.9	281.2	Poorly exposed, massive, medium- to thick-bedded, medium-grained, feldspathic and quartzose sandstone. SAMPLE DR-20 taken 2.3 m above unit base (280.6 m above base of section).
84	10.4	291.6	Massive, medium-bedded, medium-grained, feldspathic and quartzose sandstone.
85	7.5	298.1	Poorly exposed, massive, thick-bedded, medium-grained, feldspathic and quartzose sandstone. SAMPLE DR-22 taken 5.1 m above base of unit (296.7 m above base of section).
			Base of Hampton Formation, section ends. NOTE: King and Ferguson (1960) miss assigned these rocks to Unicoi Formation. Beds above this point contain abundant *Skolithos* which are visible in slabbed samples but not on outcrop (except by common purple stain seen elsewhere, I-40 section for example). Comparison with other section King and Ferguson described indicates that they generally assigned strata containing *Skolithos* to Hampton Formation. Therefore by they own definition this strata should not be assigned to the Unicoi Formation. This results in the Unicoi being at least 100 m thinner than they described.

APPENDIX B

PETROGRAPHIC DATA

The following data were collected by point counting 300 grains per thins section using the Gazzi-Dickinson method discussed in text. The parameters and various grains are list in Tables 5-1 and 5-2. I counted samples from all localities in Tennessee, data from the basal Chilhowee Group in Virginia provided by Dr. Edward L. Simpson (Assistant Professor, Kutztown University).

APPENDIX B. - *Modal abundances of recognized framework grains as determined by point-counting (percent whole rock ± 5%).*

SAMPLE#	Strat. Pos. (m)	Qm	Qp(3-7)	Qp(>7)	P	K	Lv	Ls	Lm	Other	Clay	OFFq	OFFp	OFFk	Qp	F	L
11-12-1u	184.8	92.3	1.3	0.3	0	6	0	0	0	0	0	0	0	0	1.7	6	0
11-18-1u	190	57	8.3	0	1	18.7	0	0.7	0	0	14.3	0.3	0	0	8.3	19.7	0.7
11-18-1u(c)	190	77.3	3.1	0.3	1	3.5	1	1.7	0.3	3.5	8	0	0	0	3.5	4.5	3.1
12-11-1u	196.79	77.2	0	0	3.9	10.5	5.3	2.1	0	1.1	0	0	1.4	0	0	14.4	7.4
12-11-2u	208.42	69	6.7	0.3	1	13.1	3	6.4	0	0.3	0	2	0	0	7.1	14.1	9.4
12-12-3u	210	83	3	0.7	3.3	8.3	1.7	0	0	0	0	0.3	1	0	3.7	11.7	1.7
12-13-3u	218.44	76	3.3	0	3	12.3	5	0.3	0	0	0	0.7	0.3	0.3	3.3	15.3	5.3
12-13-8u	225.64	83.7	1.3	0	3	10.7	1	0	0	0.3	0	0	0	0	1.3	13.7	1
1-7-2u	272.15	74	1.3	0	8.7	13.3	2.7	0	0	0	0	0	0	0	1.3	22	2.7
2-18-2u	272.15	64	0	0	7	25.7	3.3	0	0	0	0	0	0.3	0.7	0	32.7	3.3
1-7-5u	282.45	82	0.7	0.3	2.7	12.3	2	0	0	0	0	0.3	0.3	1.3	1	15	2
12-13-8u	282.45	82.3	1.7	0.3	4.7	4.7	1.3	0.3	0	0	4.7	0	0.7	0	2	9.3	1.7
1-7-6u	296.8	98.3	1.7	0	0	0	0	0	0	0	0	0	0	0	1.7	0	0
4-7-1u	330.06	71.2	0	0	4.7	18.7	1.7	0	0	0.7	3	0.3	0	0	0	23.4	1.7
4-28-2.5u	372.52	96.7	1.3	1.3	0	0.7	0	0	0	0	0	0	0	0	2.7	0.7	0
1-7-10u	385	83.3	0.7	0	1	10.7	0	0	0	4.3	0	0.3	0	0.3	0.7	11.7	0
W-2-90	7.1	84.5	1.7	2.1	2.8	8.3	0.7	0	0	0	0	0	0	0.3	3.8	11	0.7
W-4-90	21.1	71.9	1	2	7.5	12.7	3.6	0	0	1.3	0	0	0	0	2.9	20.3	3.6
W-5-90	21.5	77.7	4.3	0.7	4	9.3	2.7	0	0	1.3	0	0.3	0	0	5	13.3	2.7
W-9-90	42.6	77.3	2.7	0.7	4.7	11.3	3	0	0	0.3	0	1.3	0.3	0	3.3	16	3
W-10-90	44.9	86.3	2.7	0.3	0.7	8	1.7	0	0	0.3	0	0.3	0	0.7	3	8.7	1.7
W-11-90	48.2	81.3	2.7	1	4.3	9.7	1	0	0	0	0	0.3	0	0.3	3.7	14	1
W-12-90	54	84.7	3	0	1.7	10.3	0.3	0	0	0	0	0	0	0.3	3	12	0.3
W-15-90	72.4	85.7	3	0	3.3	7.3	0.3	0	0	0.3	0	0.3	0.3	0.3	3	10.7	0.3
W-16-90	78.2	75.3	1.3	0.7	3	18.3	1.3	0	0	0	0	0.3	0.3	0	2	21.3	1.3
W-17-90	82.5	80.7	2	0.7	5	10.7	0.7	0	0.3	0	0	0.3	0.7	0	2.7	15.7	1
W-18-90	82.7	75	3	0.7	6.3	13.7	0.7	0	0	0.7	0	0.7	0	0	3.7	20	0.7
WB-5-90	91	76	4	0.3	3.7	10	0.7	0	0	5.3	0	0.3	0	0.3	4.3	13.7	0.7
W-21-90	96.1	93	0.3	0	0.7	6	0	0	0	0	0	0	0	0	0.3	6.7	0
OD-S3	12.5	61.7	1.4	0.7	0.7	34.2	1.4	0	0	0	0	0	0	0	2	34.9	1.4
OD-S4	12.5	68.7	6	1	0	23	1.3	0	0	0	0	0.7	0	0	7	23	1.3
OD-S6	16.95	65.7	0.3	1.7	9.7	19	3	0	0	0.7	0	0.3	0	0	2	28.7	3
OD-S7	22.05	61.7	3	1.3	6.3	7.3	15	0.3	5	0	0	0.3	0	0	4.3	13.7	20.3
OD-S8	34.15	75	0.3	0.3	1.7	19	3.3	0	0.3	0	0	0.3	0	0	0.7	20.7	3.7
OD-S9	42.95	61.9	4.3	0	5.4	25.4	2.7	0.3	0	0	0	0	0	0	4.3	30.8	3
OD-C5	92.6	60.3	5	0.3	8.7	24.7	0.7	0.3	0	0	0	0	0.3	0.3	5.3	33.3	1
BS-C1	121.05	82.3	16.3	0.7	0	0.7	0	0	0	0	0	0	0	0	17	0.7	0
BS-C2	135.5	82.3	2	0.3	0	14.7	0	0	0	0.7	0	0	0	0	2.3	14.7	0

APPENDIX B. - *Modal abundances of recognized framework grains as determined by point-counting (percent whole rock ± 5%).*

SAMPLE#	Strat. Pos. (m)	Qm	Qp(3-7)	Qp (>7)	P	K	Lv	Ls	Lm	Other	Clay	QFFq	QFFp	QFFk	Qp	F	L
OD-C15	141.2	74.7	1.7	0.7	0	18	3.7	0.3	0.3	0.7	0	0.3	0	0.3	2.3	18	4.3
BS-C4	150.6	90	0	0.7	0	9.4	0	0	0	0	0	0	0	0	0.7	9.4	0
OD-C17	156.3	73.7	3	3.3	7.7	10.3	2	0	0	0	0	0	0.3	0	6.3	18	2
OD-C19	160	82	6.3	2	5	4	0.3	0.3	0	0	0	0.7	0	0.3	8.3	9	0.7
BS-C6	160.3	67.7	1.3	1	0	30	0	0	0	0	0	0	0	0	2.3	30	0
OD-C18	160.3	74.3	3.7	1.7	5.7	11.7	3	0	0	0	0	0.3	0	0.3	5.3	17.3	3
VCT 4.9	4.9	52.8	2.8	7.2	0.9	21.7	2.8	0	11.3	0.3	0	2.2	0.6	4.1	10.1	22.6	14.2
VCT 78.0	78	59.8	3.3	7.8	2.3	21.2	1.6	0	3.6	0.3	0	4.6	0.7	5.2	11.1	23.5	5.2
VCT 98	98	65.6	1.1	1.1	0.3	19.3	0.3	3.4	8.4	0.6	0	1.7	0	1.4	2.2	19.6	12
VCT 153	153	57.8	0.7	1.3	0	29.4	0	0	0.3	10.5	0	1	0	0.7	2	29.4	0.3
VCT 434.8	287	8.3	25	0	61.1	0	0	0	5.6	0	0	0	0	0	25	61.1	5.6
VCT 298	298	51.3	2.3	7.4	3.9	23.2	0	0	11.9	0	0	1	0	0.3	9.7	27.1	11.9
VCT 345	345	85.5	1.3	0	0.3	12.2	0	0	0.7	0	0	0	0	0	1.3	12.5	0.7
VCT 409	409	60.8	1.3	3.7	0	29.6	1.3	0.3	2.7	0.3	0	2	0	1	5	29.6	4.3
VCT 420	420	67.4	0.9	1.6	0.3	23.5	0.6	0	5.6	0	0	0.3	0	0.3	2.5	23.8	6.3
VCT 429.6	429.6	77.7	3.1	0.9	0	13	0	0	5.3	0	0	0.3	0	1.5	4	13	5.3
VCT 434	434	70.8	2.2	4.8	0	15.4	0	0	5.8	1	0	0	0	0	7.1	15.4	5.8
EC 18.3	18.3	64.7	10.1	16.3	0	1.6	0	0	5.2	2	0	4.9	0	0	26.5	1.6	5.2
EC 47.15	47.15	44.9	6.6	10.5	2.3	22.6	0	6.9	5.9	0.3	0	16.4	2	16.7	17	24.9	12.8
EC 134	134	51.9	6.3	6.9	1.9	25.9	0	0	6.9	0.3	0	6.3	0.3	7.8	13.1	27.8	6.9
EC 160.3	160.3	34.9	2.6	4.9	1	24.1	0	0	30.6	2	0	0.3	0	1.6	7.5	25.1	30.6
EC 167	167	45.7	4.4	0.3	0.6	21.6	0	0.3	26.3	0.6	0	1.6	0	2.9	4.8	22.2	26.7
EC 185.9	185.9	39.1	3.5	6.7	0.6	13.1	0	6.4	26.5	4.1	0	0	0	0	10.2	13.7	32.9
EC 191	191	53.7	4.2	3.9	1	26.4	0	0	10.7	0	0	3.3	0	3.6	8.1	27.4	10.7
EC 252A	252	33.2	0	0	0.3	9.5	27.6	0	27.3	2	0	3.6	0	0.3	0	9.9	54.9
EC 320	320	49.8	0.3	1	1	16.8	0	2	29	0	0	0.3	0	1.7	1.3	17.8	31
EC 350.5	350.5	36.2	1.3	13.3	0.7	31.2	2	11	4.3	0	0	1.3	0	3.3	14.6	31.9	17.3
EC 364	364	48.3	0.7	1.7	0.3	33.7	0	0	14.3	1	0	1	0	0.7	2.3	34	14.3
EC 386	386	70.3	5.6	1.6	0.3	20.9	0	0	0.3	1	0	2.3	0	1	7.2	21.2	0.3
EC 429.5	429.5	36.7	0.7	3.9	1.3	21	0	0	33.8	2.6	0	0.7	0	0.7	4.6	22.3	33.8
EC 434.61	434.61	86.6	0.3	1	0.7	10.4	0	0	0.3	0.7	0	0	0	0	1.3	11.1	0.3
EC 447.0	447	74.7	4.5	3.6	0	9.7	0	0	5.5	1.9	0	0	0	0	8.1	9.7	5.5
EC470A	470	54.6	4.3	19.2	0	11.3	0	0	10.6	0	0	0.7	0	1	23.5	11.3	10.6
EC 471.8	471.8	69.2	1.3	3.6	0.3	7.9	0	0	17.7	0	0	0	0	0.7	4.9	8.2	17.7
EC 496.7	496.7	81.7	5.2	0.3	0	10	0	0	2.4	0.3	0	1.7	0	1.7	5.5	10	2.4
EC 517	517	52.8	0.3	1.3	1.3	4.7	0	0	39.5	0	0	0	0	0	1.7	6	39.5
FH 1.5	1.5	64.7	3.6	11.9	0	13.4	0	0.9	0	5.5	0	2.1	0	0	15.5	13.4	0.9
FH 5.0	5	63	0.3	8.8	0	22.1	0	0	1.2	4.5	0	2.1	0	2.1	9.1	22.1	1.2

APPENDIX B. - *Modal abundances of recognized framework grains as determined by point-counting (percent whole rock ± 5%).*

SAMPLE#	Strat. Pos. (m)	Qm	Qp(3-7)	Qp(>7)	P	K	Lv	Ls	Lm	Other	Clay	QFFq	QFFp	QFFk	Qp	F	L
FH 10.0	10	68.2	8.2	3.3	0	20	0	0	0	0.3	0	3.3	0	0.3	11.5	20	0
FH 13	13	97.2	2.5	0.3	0	0	0	0	0	0	0	0	0	0	2.8	0	0
FH 15.0	15	69.3	6.1	9.4	0	6.7	0	0	2.4	6.1	0	1.2	0	0	15.5	6.7	2.4
FH 17.3	17.3	60.4	22.6	3.5	0	10.5	0	0	1.3	1.8	0	0.3	0	0	26.1	10.5	1.3
FH 23.0	23	89.3	3.6	1	0	5.2	0	0	0	1	0	0.6	0	0	4.5	5.2	0
FH 29.5	29.5	74	0.3	1.3	0	23.2	0	0	0	1.3	0	0	0	0	1.6	23.2	0
FH 43.0	43	96.4	2.3	0	0	1.3	0	0	0	0	0	0	0	0	2.3	1.3	0
BFU 0.5	0.5	11.3	0	0	0	22.7	61.2	0	1.9	2.9	0	2.9	0	17.8	0	22.7	63.1
BFU 0.5A	0.5	28.1	2.5	1.3	0.3	17.5	41.3	0	7.5	1.6	0	5.6	0	12.5	3.8	17.8	48.8
BFU 1.5	1.5	34.8	4.5	0	0	47.3	9.1	0	3.9	0.3	0	13	0	38.8	4.5	47.3	13
BFU 3.0A	3	48.1	0.6	1	0	19.4	15.5	0	13.9	1.6	0	5.2	0	2.6	1.6	19.4	29.4
BFU 3.8	3.8	38.2	1.2	0.3	0	21.1	30.4	0	4	4.7	0	10.9	0	9.6	1.6	21.1	34.5
BFU 5.1	5.1	42.7	0.6	0	0	41.8	0.3	0	13.6	0.9	0	17.7	0	27.8	0.6	41.8	13.9
BFU 12.2	12.2	32.9	0	0.3	0	31.7	27	0	5	3.1	0	11.3	0	18.8	0.3	31.7	32
BFU 18.4	18.4	41.9	1.9	1.3	1.6	26.5	9.9	0	16.3	0.6	0	2.2	0	5.1	3.2	28.1	26.2
BFU 30.8	30.8	38.2	2.6	1.3	0.3	15.5	7.6	0	26.3	8.2	0	1.6	0	1.6	3.9	15.8	33.9
BFU 39.5	39.5	37.4	2.3	2.3	0	8.3	0	0	46.7	3	0	1	0	4.6	4.6	8.3	46.7
BFU 53.0	53	29	2.2	12.9	0	10.7	0.3	0	43.5	1.3	0	1.3	0	0.3	15.1	10.7	43.8
BFU 70.01	70.01	42.7	4	1.7	0	2.6	0.7	0	43.7	4.6	0	0.3	0	0	5.6	2.6	44.4
BFU 70.02	70.02	40.1	8.4	4	0	2.7	0	0	42.5	2.3	0	0	0	0.3	12.4	2.7	42.5
BFU 99.0	99	27.3	2.5	3.1	0	4.3	0	0	57.7	5.2	0	0	0	0	5.5	4.3	57.7
BFU 120	120	37.6	0.9	0	0	23.2	0	0	36.1	2.2	0	0	0	0	0.9	23.2	36.1
BFU 128	128	38.2	0	0	0	20.2	0	3.1	37.6	0.9	0	1.2	0	0.3	0	20.2	40.7
BFU 137	137	79.3	6.9	5.3	0	3.6	0	0	4.9	0	0	0.7	0	0.3	12.2	3.6	4.9
BFU 159	159	79.7	9.6	1.3	0	0.3	0	0	9	0	0	0.3	0	0	11	0.3	9
BFU 168.2	168.2	32.1	0.6	0	0	7.1	0	2.8	45.7	11.7	0	0	0	0	0.6	7.1	48.5
BFU 172	172	36.3	0.6	0	0	12.2	0	0	50	0.9	0	0	0	0	0.6	12.2	50
BFU 178.8	178.8	48.2	1.3	0	0	9.9	0	0	39.3	1.3	0	0.3	0	0	1.3	9.9	39.3
DR-2-90	3	64	6.7	2	8.7	16.3	1	0	0	1	0.3	0.7	0.3	0.3	8.7	25	1
DR-4-90	54.5	59.3	5.7	0.3	5.7	24	4.3	0	0.7	0	0	1.3	0	0	6	29.7	5
DR-5-90	63.2	68	4	0.3	5.7	16.7	5.3	0	0	0	0	0.7	0	0	4.3	22.3	5.3
DR-6-90	65.1	68.7	4.3	1	9.7	12	4	0.3	0	0	0	0.7	1	0.7	5.3	21.7	4.3
DR-7-90	91.6	71.7	3.7	0	6.7	10	8	0	0	0	0	1.7	0.3	0.7	3.7	16.7	8
DR-8-90	100.8	61	8.3	0.7	8	12	9	0	0	1	0	1.3	0.3	1.3	9	20	9
DR-10-90	122	74	5	1.7	4.7	13.7	1	0	0	0	0	0.7	0.7	0.3	6.7	18.3	1
DR-11-90	131.2	67.7	14.3	0	3.7	11.7	2.7	0	0	0	0	4.3	0.3	0	14.3	15.3	2.7
DR-12-90	143.5	71	12	0.3	3.7	10.7	2.3	0	0	0	0	2.3	0	1.7	12.3	14.3	2.3
DR-13-90	155.9	68.6	9.7	0	5	9.4	5.7	0.3	0	1.3	0	2.3	0.7	0.3	9.7	14.4	6

APPENDIX B. - *Modal abundances of recognized framework grains as determined by point-counting (percent whole rock ± 5%).*

SAMPLE#	Strat. Pos. (m)	Qm	Qp(3-7)	Qp (>7)	P	K	Lv	Ls	Lm	Other	Clay	QFFq	QFFp	QFFk	Qp	F	L
DR-15-90	204.9	68.7	13.3	0.3	5	9	3.7	0	0	0	0	3.3	1.7	1	13.7	14	3.7
DR-16-90	223.4	69.3	14	0	4.3	10.3	1.7	0	0	0.3	0	2.7	1	0	14	14.7	1.7
DR-17-90	237.1	87.7	9.3	0	0.3	2.3	0.3	0	0	0	0	2.3	0	0	9.3	2.7	0.3
DR-18-90	257.2	91.6	4.7	0	1.3	2.3	0	0	0	0	0	0.3	0	0	4.7	3.7	0

APPENDIX C

BASALT TRACE ELEMENT DATA

The following data were collected by X-ray florescence spectroscopy at the University Of Tennessee. Basalt sample groups VC, MB, and M were collected from the Montezuma Member of the Grandfather Mountain Formation, Grandfather Mountain window, North Carolina. Sample groups A and VCT were collected from localities of the Unicoi Formation of the Chilhowee Group in Virginia. Sample groups E, LB, SG, and DR were collected from localities of the Unicoi Formation of the Chilhowee Group in Tennessee. Sample BR- 1 was collected from the Bakersville dike swarm, west of the Grandfather Mountain window.

APPENDIX C. -*Trace element abundances as determined by X-ray florescence spectroscopy (expressed as weight percent).*

SAMPLE	NA2O	MGO	AL2O3	SIO2	P2O5	K2O	CAO	MNO	TIO2	V	CR	FE2O3	NI	RB	SR	Y	ZR	NB	Total
A-1A	3.76174	5.45392	12.94485	51.50352	0.11261	0.27101	4.46128	0.26723	3.11937	0.01602	0.01557	14.93405	0.00590	0.00093	0.02181	0.00535	0.01739	0.00169	96.91424
A-1B	3.15672	6.43854	12.47549	49.57014	0.06048	0.34370	3.42371	0.30755	2.97717	0.01487	0.02649	18.07667	0.00914	0.00086	0.02918	0.00411	0.01578	0.00167	96.93227
A-1C	3.64233	7.15819	13.66515	46.92107	0.10637	0.38018	4.87471	0.36194	2.99460	0.01652	0.02313	18.21087	0.00880	0.00096	0.02888	0.00386	0.01620	0.00171	98.41547
A-2	4.43419	4.31258	13.55794	50.73173	0.12892	0.57921	6.95599	0.26773	3.09315	0.02077	0.01366	13.71577	0.00499	0.00188	0.02765	0.00424	0.01770	0.00174	97.86984
A-3	2.43871	6.98884	13.01253	49.83630	0.11832	0.32238	5.23060	0.44469	2.95469	0.01724	0.01794	15.19746	0.00750	0.00108	0.01793	0.00440	0.01619	0.00157	96.62837
A-4	3.38757	4.80825	12.67168	50.31664	0.09347	0.43512	4.59106	0.33895	2.70183	0.01608	0.02149	17.34770	0.00956	0.00115	0.02196	0.00362	0.01537	0.00165	96.78315
A-5	3.27392	2.46015	13.57565	46.02846	0.18623	1.06246	13.59064	0.43285	3.13835	0.04324	0.00835	13.28927	0.00223	0.00571	0.01583	0.00432	0.01603	0.00140	97.13509
DR-1	0.55649	10.09225	13.18629	42.52622	0.07226	0.89498	6.34882	0.20030	2.93593	0.02042	0.02495	18.50756	0.01436	0.00090	0.02630	0.00401	0.01363	0.00136	95.42703
DR-4	0.39833	11.06356	12.73919	44.75422	0.05258	1.85339	2.13314	0.10012	2.61536	0.01416	0.03470	18.69380	0.01467	0.00085	0.00706	0.00413	0.01246	0.00144	94.49316
E-2	4.00311	7.37045	16.54646	50.46118	0.04623	0.61661	2.08613	0.07215	2.47662	0.01100	0.01567	11.26749	0.00939	0.00057	0.01323	0.00454	0.01434	0.00149	95.01666
E-6	3.83593	8.88169	17.45902	44.96400	0.00539	0.65147	2.16599	0.10429	2.41876	0.01160	0.02042	14.47640	0.01057	0.00066	0.01535	0.00422	0.01360	0.00157	95.04093
LB-1	1.37804	8.28758	12.30779	48.84459	0.10401	0.24098	6.93607	0.28320	2.71647	0.02093	0.02332	16.16997	0.01178	0.00044	0.06897	0.00282	0.01689	0.00120	97.41505
LB-2	1.93651	8.12240	13.09882	48.74852	0.15118	0.42329	8.39249	0.28964	2.78804	0.02504	0.01718	14.71169	0.00815	0.00091	0.08300	0.00251	0.01823	0.00133	98.81893
LB-3	1.81412	8.73045	12.72505	48.51974	0.05217	0.36510	4.83646	0.26863	2.51328	0.01711	0.02313	16.77556	0.01262	0.00067	0.06438	0.00271	0.01567	0.00117	96.73802
SG-6	0.85777	4.19113	20.82018	45.45346	0.14578	7.31212	0.78615	-0.02775	3.75723	0.00821	0.02542	17.28948	0.01525	0.01430	0.00270	0.00428	0.01663	0.00173	100.67407
VCT-1	2.37740	4.85072	13.49194	55.44267	0.16262	1.15370	6.59937	0.34145	2.73239	0.01996	0.01861	12.60257	0.00689	0.00190	0.03146	0.00313	0.01545	0.00127	99.85350
VCT-3	1.97589	8.63273	13.36131	48.81268	0.11980	0.45062	6.56651	0.21915	2.82022	0.02032	0.02237	14.25540	0.01300	0.00091	0.02661	0.00367	0.01492	0.00128	97.31739
M-1	2.71644	7.00352	14.98906	46.31905	0.22030	0.88895	7.66703	0.17622	3.20569	0.02203	0.01615	16.36022	0.00803	0.00159	0.03232	0.00303	0.01417	0.00146	99.64526
M-2	3.28236	5.92504	15.54809	48.01678	0.36203	3.02967	6.76074	0.23628	2.92995	0.02065	0.01817	15.99661	0.00749	0.00530	0.04055	0.00293	0.01540	0.00144	102.19948
M-4	2.38246	7.77941	16.02548	46.26557	0.28361	2.74716	4.35419	0.33286	3.58157	0.01468	0.02538	16.82663	0.01030	0.00342	0.04796	0.00296	0.01519	0.00163	100.70046
MB-1	4.49187	5.58979	13.77699	45.78122	0.63466	1.41598	5.55534	0.20869	3.77060	0.01510	0.01947	21.58466	0.00683	0.00112	0.01083	0.00637	0.02264	0.00308	102.89524
MB-3	5.62578	3.77344	12.10616	56.99957	0.12878	0.48565	3.37995	0.10640	2.35026	0.01204	0.01614	14.48612	0.00899	0.00079	0.00894	0.00306	0.01297	0.00152	99.50656
VC-1	4.24629	4.39502	13.09592	49.69904	0.76513	2.33637	5.56589	0.18087	3.34717	0.01656	0.01630	18.31324	0.00477	0.00230	0.01551	0.00677	0.02396	0.00309	102.03420
VC-2	4.45662	4.20796	13.10724	51.05190	0.93170	1.31648	5.59808	0.16611	3.09027	0.01537	0.01338	17.18150	0.00502	0.00116	0.01865	0.00761	0.02615	0.00329	101.19849
VC-3	5.10938	6.03190	13.37287	48.72843	0.65628	1.04558	5.52585	0.24530	3.50165	0.01536	0.01490	17.68195	0.00446	0.00091	0.01461	0.00671	0.02427	0.00313	101.98354
VC-3	4.79748	5.98352	13.36724	48.68681	0.65757	1.04047	5.52378	0.24257	3.48674	0.01574	0.01314	17.39815	0.00418	0.00091	0.01388	0.00662	0.02401	0.00292	101.26573
VC-4	4.02671	5.41234	13.18191	47.72751	0.61057	1.52159	6.32679	0.20780	3.48117	0.01766	0.02052	19.01250	0.00472	0.00147	0.02251	0.00620	0.02266	0.00294	101.60757
VC-6	2.97875	3.97971	13.10042	52.34886	0.91336	3.32023	4.77393	0.15230	2.85348	0.01487	0.01790	17.34239	0.00365	0.00285	0.01314	0.00671	0.02305	0.00296	101.84856
VC-8	2.76437	6.71528	14.42916	44.93763	0.52598	2.52014	5.73907	0.24611	3.99760	0.01666	0.02048	18.96783	0.00589	0.00252	0.00887	0.00664	0.02203	0.00267	100.92893
BR-1	1.95019	4.90294	13.72987	45.20533	0.25089	2.11183	8.58501	0.18854	2.94030	0.02467	0.01751	16.18945	0.00474	0.01183	0.04623	0.00309	0.01651	0.00141	96.18034

VITA

James Daniel Walker was born in Denver, Colorado on April 28, 1960. After living in Denver for five years his family re-located to Smithville, Missouri, in October 1965. He attended kindergarten through the third grade at Smithville Elementary School. In August 1968, his family moved to a small farm outside of Gower, Missouri were they operated a small family farm for many years. Dan attended grades 4 - 12 at East Buchanan C-1 at Gower, Missouri. While attending high school he was an All-Conference line-backer and co-captain of his football team, editor of the high school annual, and president of both his Junior and Senior class. In May 1978, he graduated with honors. Dan then attended The University of Alabama and double majored in geology and marine science. He attended classes through the Dauphin Island Marine Science Consortium at Dauphin Island, Alabama. In December 1982, he graduated with a B.S. in geology. In January 1983, Dan began classes in geology at New Mexico State University in Las Cruces, New Mexico as a graduate assistant. While in Las Cruces, he completed a master's thesis entitled "The Tectonics and Sediment Dispersal of the Hayner Ranch and Rincon Valley Formations (Miocene): San Diego Mountain, Dona Ana County, New Mexico" under the direction of Dr. Greg H. Mack. During this time, he began his life-long love of mexican cooking and learned to make a fair margarita. He received his Master's in geology in May, 1986.

Dan entered the Department of Geological Sciences at the University of Tennessee in Knoxville, Tennessee in September 1985, as a graduate teaching assistant. In August 1989, he was appointed graduate teaching associate and allowed to teach his first undergraduate lecture class in physical geology. While attending the University of Tennessee, Dan was awarded the department's C. H. Gordon award (Outstanding Professional Promise) and served as President of the Gamma Gamma Chapter of Sigma Gamma Epsilon. He received his Doctorate of Philosophy with a major in geology in May, 1990.